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Towards additional policies to improve the environmental performance of buildings

Part II: Quantitative assessment

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Executive summary

The building stock is one of the major sources of environmental impacts because it contributes to about 40 % of energy consumption and 25 % of greenhouse gas emissions in the European Union. This is why policies exist or have been proposed at EU level to improve the energy efficiency of buildings. Existing and already proposed policies address mainly new buildings and major renovations of existing buildings.

This report presents the results and conclusions of research carried out by the European Commission's Joint Research Centre - Institute for Prospective Technological Studies (JRC-IPTS) analysing energy efficiency measures in the residential building sector. The first part of this study, the qualitative assessment has shown that – on top of the policies already in place or in the pipeline – there is the potential for additional energy efficiency policies to lead to further reductions in the environmental impacts. Improving the energy efficiency of certain building elements such as windows and roofs independently of major renovations of whole buildings was identified as potential main target of such additional policies.

This report covers the second part of the study and offers a quantitative assessment of the possible environmental and socio-economic effects. Two types of measures addressing the energy efficiency of building elements are assessed: 1) requiring high energy efficiency standards (thermal insulation levels) when individual building elements have to be renovated, and 2) accelerating the retrofitting of individual building elements according to high energy efficiency standards.

The quantitative assessment is based on a detailed modelling of the building stock and its energy performance in three Member States of the EU: Germany, Spain and Poland. The study not only analyses the direct effects of the energy efficiency measures, such as capital costs, energy savings, and direct greenhouse gas emission reductions, but models also the economy-wide repercussions on parameters including employment, value added, or welfare.

The results of the modelling show that additional policies could deliver further substantial savings of energy and greenhouse gas emissions and that the socio-economic benefits would outweigh the costs.

In a scenario in which the renovation and refurbishment of windows, wall insulation and roof insulation is always performed according to the cost optimal[1] energy efficiency level, an additional 25 % to 40 % of energy for room heating and associated greenhouse gas emissions can be saved compared to the savings expected from existing and already formally proposed EU policy instruments. In this scenario the energy cost savings outweigh the additional capital investment after about 10 to 15 years.

The report does not assess specific policy instruments for introducing such measures. However, setting minimum performance requirements for building elements close to the cost optimal level would be one of the options. This may be considered for example in the framework of the Eco-design Directive when its scope is extended to energy-related products. A combination of minimum performance requirements with ecolabel or energy label schemes might also be an option.

The accelerated replacement of building elements compared to the normal renovation cycles is assessed as the second type of potential additional measures. Different scenarios were included assuming the faster replacement of either roofs or windows or both elements. The additional reduction

[1] The cost-optimal energy efficiency level is defined as the energy efficiency level at which the annual costs (composed of capital/investment cost and energy cost savings) are lowest.

of energy use and greenhouse gas emissions amount to about 10 % compared to the not accelerated scenarios. However, the acceleration of the replacement of building elements before they have reached their end of life comes with certain disadvantages. The cost efficiency of these scenarios is comparably low and in some cases there are even net costs. In addition, individual sectors of the economy would be highly affected (both positively and negatively) which might lead to adjustment problems. For certain countries, the accelerated retrofitting of single building elements might be recommendable but this has to be studied carefully in advance and in greater detail.

The effects of the assessed policy measures vary from country to country due to differences in the parameters influencing the policy impacts. This includes e.g. climate, the current energy efficiency level of the building stock, the development of the building stock in the past and the expected building stock development in the future, the typology of the building stock (e.g. the share of high-rise buildings), energy costs, and the cost of refurbishment measures. An assessment of specific policies towards energy efficiency in the building stock should thus be performed on a country-by-country basis.

It is also important to mention that the energy efficiency levels assumed at cost optimality are not very ambitious compared to low-energy and passive house standards, which are likely to offer even further improvement potentials especially regarding new buildings. Also measures that improve energy efficiency by a replacement of heating systems, the insulation of floors and interior walls have not been assessed in this study.

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Glossary

EE	Energy efficiency
EPBD	Energy Performance of Buildings Directive
EuP	Energy-using product
GFCF	Gross Fixed Capital Formation
HR	High-rise building
GHG	Greenhouse gas
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
MF	Multi-family house
MR	Major renovation
NACE	Nomenclature des activités économiques dans la Communauté Européenne
RR	Roof refurbishment
SI	Single-family house
SCP	Sustainable Consumption and Production
VA	Value Added
VAT	Value Added Tax
WR	Window refurbishment

Part A: Synthesis report

1 Introduction

1.1 Background

The housing sector is one of the major sources of environmental impacts [Eder & Delgado 2006]. Worldwide, as well as in the European Union, the building stock is responsible for 40 % of the primary energy consumption and about 25 % of the CO_2 emissions [OECD/IEA 2008]. In the EU, residential buildings are responsible for 27 % of final energy demand (including space heating, cooking, lighting, water heating, and electrical appliances).

There exist a vast number of measures and options to reduce both the energy use and the environmental impacts from buildings. Most of these options are cost effective, however, a great share of the improvement potential remains untapped so far [Nemry et al. 2008]. The unused potential for energy efficiency improvements is usually referred to as the energy efficiency gap [OECD/IEA 2008, The Allen Consulting Group 2004].

An assessment of the Institute for Prospective Technological Studies (JRC-IPTS)[2] has shown that there are already many existing and planned policies at EU and national levels that address the energy efficiency gap in the housing sector [Uihlein & Eder 2009]. The main building block of the EU regulatory framework is the energy performance of buildings directive (EPBD) [OJL 001 2003]. Currently, the reinforcement of this directive is in the approval process. Most probably, also small buildings will be included in the scope of the directive and the potential of 'low or zero energy' or 'passive' houses will be addressed.[3] Overhauls have also been prepared for the eco-design and energy labelling directives within the framework of the EU policies on sustainable consumption and production (SCP) [COM(2008) 397 final]. Together these measures may achieve an important part of the potentially available cost-effective energy-savings in buildings. However, a recent JRC-IPTS report has shown in principle that – besides the policies in place or planned already – there is the potential for additional policies to lead to additional improvements [Uihlein & Eder 2009]. To analyse these measures in detail is the purpose of this study.

The EPBD focuses mainly on energy efficiency measures when new buildings are constructed or when existing buildings undergo major renovations. Consequently, this allows to make the energy efficiency investments at least cost, because they form part of the natural construction and renovation cycles. However, major renovations of buildings are not made very often (about every 40 years on average) and there might exist energy efficiency measures that are cost-effective also outside the major renovation cycles [Uihlein & Eder 2009]. In particular, the retrofitting of windows and roof insulation to reduce energy losses may allow energy cost savings that outweigh the investment costs, without the need to carry these measures out at the same time as a general major renovation of the building [see e.g. Nemry et al. 2008]. Currently there is no European legislation that would address the retrofitting of building elements such as windows and roofs. Potentially, this was shown to be the most important area for additional policies in the EU to improve the environmental performance of buildings [Uihlein & Eder 2009].

[2] IPTS is one of the seven research institutes of the European Commission's Joint Research Centre (JRC).

[3] European Parliament press release from 23 April 2009 (http://www.europarl.europa.eu/news/expert/infopress_page/051-54164-111-04-17-909-20090422IPR54163-21-04-2009-2009-false/default_en.htm).

There are two main types of actions by which the retrofitting of the existing building stock (independently of major renovations) may offer substantial additional energy efficiency gains and associated environmental improvement potential: the introduction of minimum performance requirements when building elements are renovated or put in for the first time, and acceleration of the retrofitting of individual building elements according to higher energy efficiency standards [Uihlein & Eder 2009]. Both these options have been investigated in this study.

1.2 Objectives

The objective of this study is to assess quantitatively the possible environmental and socio-economic effects of additional policies in the EU to improve the energy efficiency of residential buildings. The additional policies consist in measures aiming at retrofitting individual elements of the building envelope that show low thermal performance also outside the major renovation cycles – which is new compared to existing and already proposed EU policies, which focus on energy efficiency of new buildings and major renovations.

Different policy scenarios are defined and modelled in which improved thermal insulation levels are required when building elements, such as windows and insulation of roofs and walls, are newly installed or renovated. In some of the scenarios the retrofitting according to these improved insulation levels is furthermore accelerated compared to normal renovation cycles.

The study not only analyses the direct effects of the energy efficiency measures, such as capital costs, energy savings, and direct greenhouse gas emission reductions, but models also the economy-wide repercussions on parameters including employment, value added, or welfare.

1.3 Reading guide

This report is divided into two parts. The overall results of the study and the main conclusions are presented in Part A (Synthesis report, Chapters 1 to 4). The full report including the methodology and more detailed results can be found in Part B (Full report, Chapters 5 to 10).

2 Methodological approach

The first task in this study was the definition of policy scenarios that increase the energy efficiency of the residential building. As a base case, a scenario was assumed comprising the existing and planned policy measures like e.g. the recast of the EPBD. Starting with this base case, various policy scenarios were defined that include additional measures that go beyond the existing and planned instruments.

The policy scenario modelling was performed for three selected countries: Germany, Spain and Poland. This selection was made to include countries with big building stocks in different climatic zones in Europe and from the groups of both old and new Member States. No country from northern Europe was selected as the potential volume of greenhouse gas emission and energy savings is small in this region compared to south and middle Europe [Nemry et al. 2008].

The modelling approach in this study consisted of two subsequent steps (Figure 1). First, a building stock model was set up to calculate the building stock development according to six building types (e.g. new single-family houses, existing single family-houses) for each country. The building stock model served to calculate the renovation and refurbishment activity on an annual basis (e.g. roof refurbishment in m^2 roof area in 2015). The building stock model was also used to calculate the energy demand and greenhouse gas emissions from space heating by households. The building stock model is presented in detail in Chapter 5.

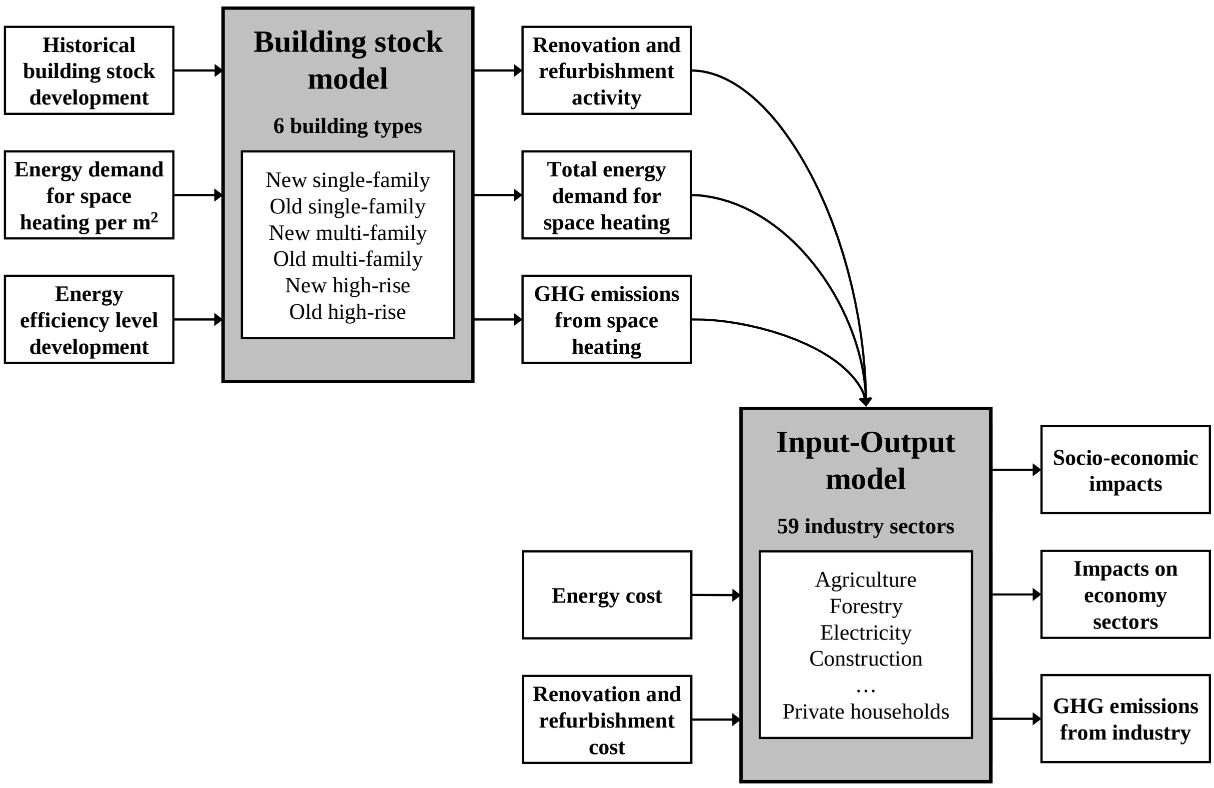

Figure 1 General overview of the modelling approach and project structure

In a second step, the results of the building stock model amended with energy cost data as well as renovation and refurbishment cost data (see Chapter 6) were transferred into the input-output modelling framework. The input-output model was used to calculate economy-wide impacts on indicators like value-added, employment, welfare and GHG emissions from industry. Different macroeconomic options of financing the measures were modelled. In addition, the input-output model was used to assess the impacts of the policy scenarios on individual sectors of the economy. A description of the input-output methodology and the data used for modelling can be found in Chapter 7.

3 Summary of the results

The modelling results confirm the impact assessment of the legislative proposal for the EPBD recast showing that extending minimum energy performance requirements to all building sizes, as proposed for the recast, will lead to significant reductions of energy demand and greenhouse gas emissions [COM(2008) 755].

The analysis of possible additional policies shows that further substantial savings of energy and greenhouse gas emissions are possible with socio-economic benefits outweighing the costs. In a policy scenario in which the renovation and refurbishment of windows, wall insulation and roof insulation is always performed according to the cost optimal[4] energy efficiency level, an additional 25 % to 40 % of energy for room heating and thus greenhouse gas emissions can be saved. In this scenario, the renovation and refurbishments are not accelerated, i.e. they take place at the same time as without additional policies The main difference to the base case is that such additional policies would aim at cost optimal energy efficiency levels not only at the occasion of major renovations but also for the retrofitting of individual building elements like roofs and windows. The cost of the additional investment needed for this scenario is compensated by the energy savings achieved after some years with a payback period between 10 to 15 years (depending on country). The scenario thus comes at negative net costs for consumers. The socio-economic impacts of this policy scenario indicate that the measures are feasible with small effects that are positive for a majority of the indicators.

The additional energy and greenhouse gas saving would be even higher if the retrofitting of building elements were accelerated compared to the normal renovation cycles. The acceleration of the installation of building elements at cost optimal energy efficiency levels was covered by different policy scenarios assuming acceleration either of roof refurbishment or window refurbishment only or assuming an acceleration of the exchange of both building elements. In general, these scenarios offer the potential for additional energy savings and GHG reductions of about 10 % compared to the non-acceleration. However, our model indicates that this additional saving potential comes with certain disadvantages. First, the cost efficiency of these scenarios is low, in some cases, positive net costs can occur. Also, the socio-economic impacts can be negative. In addition, the policy scenarios show significant impacts on individual sectors of the economy (both positive and negative) which might lead to adjustment problems.

For all policy scenarios, but especially for the scenarios that imply an acceleration of refurbishment, the results vary from country to country. This can be explained by differences in climate and in the existing energy efficiency level of the residential building stock (see Section 3.5). The results of the environmental and socio-economic assessment will be presented in greater detail in the following sections with a focus on the main and most significant policy scenarios investigated. Further information and a detailed presentation of the results can be found in Chapter 9.

3.1 Results of the base case (EPBD recast scenario)

As a base case of the present study, a scenario according to the EPBD recast was assumed. This scenario comprises the full implementation of the policies included into the Commission proposal on the recast of the EPBD [COM(2008) 780 final]. It was assumed that until 2005, the EPBD recast

[4] The cost-optimal energy efficiency level is defined as the energy efficiency level at which the annual costs (composed of capital/investment cost minus the energy cost savings) are lowest. Annual costs can be both positive or negative.

scenario is identical to the reference scenario (the reference scenario assumes no further efficiency improvement from 2008 on). From 2006 to 2011, it was assumed that new buildings and the major renovation[5] of buildings above the threshold of 1 000 m^2, national minimum performance requirements are met. From 2012 on, these requirements apply to all new buildings and major renovations without a size limit. From 2013 to 2016, it is assumed that all subsidised construction and major renovation is carried out so as to attain the cost optimal energy efficiency levels, all other new construction and major renovation is done according to the ‘old’ minimum performance requirements. From 2017 on, all new construction and major renovation applies cost optimal energy efficiency measures.

The average energy savings of the base case are quite considerable and range from 5.9 % to 7.6 % of the annual energy demand of households for space heating depending on country (Table 1). Concerning the total final energy consumption of households, the reduction ranges from 3.3 % to 4.2 %. The greenhouse gas emissions caused by households can be reduced by 2.6 % to 3.4 %. Total national emissions (including feedback effects within the economy) can be reduced by around 0.7 % to 2.3 %, depending on country.

These findings are inline with the results of the EPBD recast impact assessment which estimated the energy savings in the EU to about 840 PJ and the greenhouse gas emission savings to around 51 Mt CO_2 in 2020 [COM(2008) 755]. The energy savings calculated in the present study amount to about 240 PJ annually for the three countries (Germany, Spain, and Poland) while the annual GHG emission savings are around 23 Mt.[6]

Table 1 Average annual energy and GHG emission savings for the EPBD recast scenario

Country	Energy savings of households			GHG emission savings by households			Total national GHG emission savings	
	PJ	% of final energy use for space heating	% of total final energy use[a)]	Mt CO_2-eq.	% of space heating[b)]	% of total[c)]	Mt CO_2-eq.[d)]	% of total national GHG emissions
Germany	157.3	7.6	4.2	7.5	7.6	3.4	15.1	1.6
Spain	38.7	7.1	4.0	1.6	7.1	3.2	4.4	0.7
Poland	40.5	5.9	3.3	1.4	5.9	2.6	3.9	2.3

a) Including electricity; b) Including only GHG emissions from boilers in households (e.g. gas, heating oil) and excluding emissions from electricity production; c) Including all upstream emissions due to the production and provision of electricity, district heat, and other fuels; d) Including also emission reductions due to changes in economic activity and feedback loops between the sectors of the economy

The results of the socio-economic assessment of the EPBD recast scenario are presented in Table 2 with the bandwidth of the results displaying the possible range of the impacts according to the different financing options. For the majority of the financing options, positive socio-economic impacts can be expected, e.g. increase in employment, or welfare. In general, the impacts are very small. For example, the change in total employment ranges from -0.01 % to 0.04 % in Germany.

The impact assessment of the EPBD recast assumes that the job creation in 2020 would amount to about 75 000 new jobs [COM(2008) 755]. The estimations of this study confirm the results of the impact assessment: The calculated employment effects range from 12 000 to 68 000 jobs in the three countries together (big effects occur in Spain and small effects in Germany and Poland), depending on financing option. The net costs (the additional expenditure for refurbishment or renovation minus the

[5] In this study, major renovation comprises the renovation of exterior walls as well as the retrofitting of roofs and windows.

[6] This corresponds to approximately 64 Mt for all EU countries when using data from EEA on total GHG emissions for all EU countries to interpolate (http://www.eea.europa.eu/publications/eea_report_2008_5). Using the same share, the energy savings for the EU27 are about 670 PJ.

saved energy costs) for households including taxes amount to about -26 600 Mio. Euro for the years 2000-2060 in the three countries which corresponds to an annual saving of about 440 Mio. Euro.

Table 2 Results of the socio-economic assessment of the EPBD recast scenario (average from 2000 to 2060)

Indicator	Unit	Germany	Spain	Poland
Value added	Mio. Euro/a	-122 to 538[a)]	58 to 265	-15 to 30
	%	-0.01 to 0.03	0.01 to 0.07	-0.02 to 0.03
Employment	1000 employees/a	-4 to 16	18 to 50	-3 to 2
	%	-0.01 to 0.04	0.04 to 0.12	-0.04 to 0.04
Compensation of employees	Mio. Euro/a	-390 to 103	29 to 128	-32 to 8
	%	-0.04 to 0.01	0.01 to 0.06	-0.06 to 0.02
Tax revenue	Mio. Euro/a	-2 to 117	-55 to 40	-19 to 4
	%	0.00 to 0.21	-0.19 to 0.14	-0.31 to 0.07
Welfare[b)]	Mio. Euro/a	-143 to 431	424 to 638	114 to 163
	%	-0.01 to 0.03	0.08 to 0.12	0.08 to 0.11
Net costs	Mio. Euro	-15 471	- 8 326	-2 787

a) The results are the bandwidth of the different financing options of the policy; b) Welfare is measured by the net effects on available budget. If, for example, the energy cost savings exceed the additional expenditure, a positive welfare effect is assumed. Also indirect effects due to the recycling of tax revenue and the compensation of employees are taken into account.

It has to be kept in mind, however, that the modelling framework applied in this study entails some limitations. First, the financing options were used to test the bandwidth of results. The range of the model results for the different financing options should thus be seen as extreme values. Second, the modelling of the financing options is limited only to a shift of investment or expenditure. It was assumed that the total budget remains constant (zero-sum) which does not allow for expanding consumption and/or investment in one year and decreasing in other years. In addition, the model assumes instantaneous adjustment of the economy (e.g. full capital and labour mobility). Other uncertainties are due to limited data availability or robustness but the sensitivity analyses performed confirmed the conclusions of the modelling (see Section 9.4). Further information on some modelling limitations can be found in Section 3.5.

3.2 Renovation & refurbishment at cost optimal level

This policy scenario assumes that whenever major or minor refurbishment actions have to be made to the envelope of the building, the cost optimal energy efficiency level is installed [‘cost optimal’ defined following ECOFYS 2005a, ECOFYS 2005b].[7] In this study, immediately (from 2009 on), a full cost optimal refurbishment of the following building elements was assumed: exterior walls, windows, and roofs.

To approach this scenario, additional policy measures would be needed that amend the existing ones. These measures would have to assure that whenever renovation or refurbishment takes place, the new building element installed features cost optimal energy efficiency. Policy instruments that could be used include e.g. minimum performance requirements for roofs which regulate the minimum thickness of insulation (depending on roof type, material type, and installation mode) and prescribe certain installation quality standards. In addition, minimum performance requirements for windows (e.g. definition of cost optimal U-values) and exterior walls will be needed. Minimum performance

[7] If additional insulation is added, there will be a minimum for the annual overall costs which is a sum of annual capital costs and annual saved energy costs, depending on insulation level.

requirements could be defined through e.g. the Ecodesign Directive when it will be extended to energy-related products or other suitable policy instruments and complemented by financing measures [Uihlein & Eder 2009, COM(2008) 399].[8]

By installing only building elements according to cost optimal energy efficiency level, the energy and GHG emission savings are higher than for the EPBD recast scenario. The results show that the energy savings in household can be increased by about 73 PJ which corresponds to about 30 % of the savings in the EPBD recast scenario.

The total energy use of households can be reduced by 4.1 % to 5.6 % compared to the reference scenario (3.3 % to 4.2 % in the EPBD recast scenario) while GHG emissions due to households are reduced by 3.3 % to 4.4 % depending on country (Table 3). The total GHG emissions of the economy can be reduced by around 1.0 % to 2.9 %. The GHG emission savings are between 25 % and 40 % higher than for the EPBD recast scenario depending on country.

Table 3 Average annual energy and GHG emission savings for renovation & refurbishment at cost optimal level

Country	Energy savings of households			GHG emission savings by households			Total national GHG emission savings	
	PJ	% of final energy use for space heating	% of total final energy use[a)]	Mt CO_2-eq.	% of space heating[b)]	% of total [c)]	Mt CO_2-eq.[d)]	% of total national GHG emissions
Germany	204.1	9.9	5.5	9.7	9.9	4.4	19.6	2.0
Spain	54.8	10.1	5.6	2.3	10.1	4.5	6.2	1.0
Poland	50.8	7.4	4.1	1.8	7.4	3.3	4.9	2.9

a) Including electricity; b) Including only GHG emissions from boilers in households (e.g. gas, heating oil) and excluding emissions from electricity production; c) Including all upstream emissions due to the production and provision of electricity, district heat, and other fuels; d) Including also emission reductions due to changes in economic activity and feedback loops between the sectors of the economy

The installation of building elements according to cost optimal energy efficiency levels induces come at higher cost (Figure 2). At the same time, this leads to energy and energy cost savings. The example for Germany shows that in the first years, the additional investment needs are greater than the energy savings. Subsequently, the energy cost savings increase and from around 2025, they exceed the additional investments, in general. The breakeven point is reached earlier in Poland and Spain (around 2015).

The results of the socio-economic assessment suggest that – on average – the impacts on value added and employment are positive for almost all financing options (Table 4). Welfare is increased for all options in all countries except for Germany. The best results are obtained when the additional investment needed is provided by a shift of investment (less investment in non-construction related sectors of the economy).[9] The energy cost savings should be left with the households. Households should spend the money on other consumption items (shift from energy to non-energy). If, instead, households save the money, the positive impacts are slightly reduced but still positive. The same applies when the investment is made by households while reducing their expenditure on consumption items. When the government finances the investment, in general, the socio-economic impacts are less favourable compared to other financing schemes.

[8] The examples of the revision of the EuP-Directive indeed include construction products such as windows, and insulation materials.

[9] However, it has to be kept in mind, that the model does not cover the negative effects of a reduction of investment on the production base.

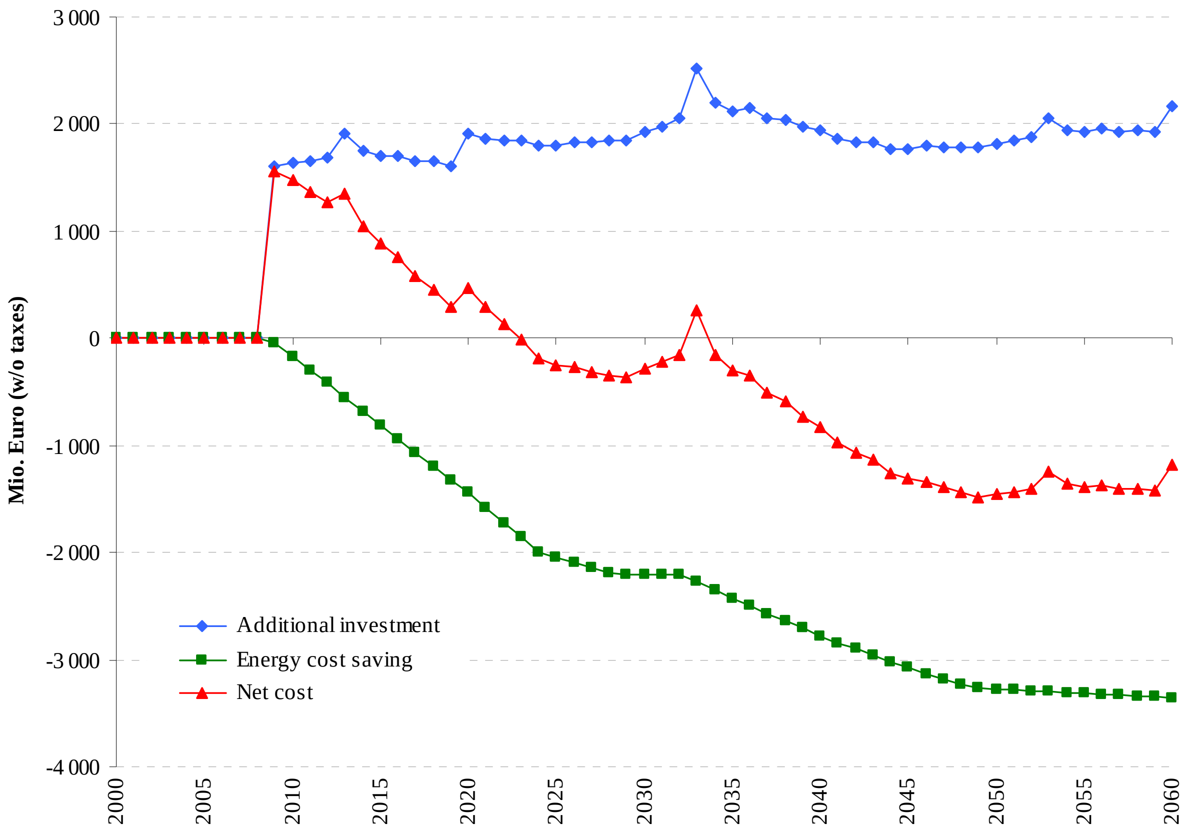

Figure 2 **Additional investment, energy cost savings and net costs for cost optimal renovation & refurbishment in Germany**

The range of the socio-economic effects of the installation of cost optimal building elements are greater than in the EPBD recast scenario but the relative impacts are – on average – still small (up to a maximum of 0.5 %). For most socio-economic indicators, the cost optimal renovation and refurbishment scenario leads to better socio-economic results. The net costs for households (including taxes) are approximately -44 300 Mio. Euro for the years 2000-2060 in the three countries which corresponds to an annual saving of about 730 Mio. Euro.

Table 4 **Results of the socio-economic assessment for cost optimal renovation & refurbishment (average from 2000 to 2060)**

Indicator	Unit	Germany	Spain	Poland
Value added	Mio. Euro/a	-139 to 698[a)]	69 to 312	-17 to 39
	%	-0.01 to 0.04	0.02 to 0.08	-0.02 to 0.04
Employment	1000 employees/a	-5 to 20	22 to 56	-3 to 3
	%	-0.01 to 0.06	0.05 to 0.12	-0.05 to 0.05
Compensation of employees	Mio. Euro/a	-490 to 135	34 to 151	-40 to 10
	%	-0.04 to 0.01	0.02 to 0.07	-0.08 to 0.02
Tax revenue	Mio. Euro/a	-4 to 151	-65 to 47	-30 to 5
	%	-0.01 to 0.27	-0.23 to 0.17	-0.50 to 0.09
Welfare[b)]	Mio. Euro/a	-135 to 594	490 to 740	144 to 205
	%	-0.01 to 0.04	0.09 to 0.13	0.10 to 0.14
Net costs	Mio. Euro	-23 230	-17 356	-3 670

a) The results are the bandwidth of the different financing options of the policy; b) Welfare is measured by the net effects on available budget. If, for example, the energy cost savings exceed the additional expenditure, a positive welfare effect is assumed. Also indirect effects due to the recycling of tax revenue and the compensation of employees are taken into account.

3.3 Replacement of building elements with low energy efficiency before reaching end of life

The cost optimal scenario assumed the refurbishment of individual building elements taking place within the regular retrofitting cycle. In addition, one could imagine the replacement of building elements with low energy efficiency before they have reached their end of life, thus, the retrofitting cycles would be shortened.

A policy scenario was developed that is based on the cost optimal renovation & refurbishment scenario (see Section 3.2). In addition to the measures applied there, between 2009 and 2018, all roofs and windows of the building stock that are older than 10 years and that are not at cost optimal level, are refurbished and new building elements are installed at cost optimal level. This means, that by 2018, all roofs and windows comply with cost optimal energy efficiency levels. After 2018, the normal refurbishment cycle is applied again. In addition, also other policy scenarios were developed assuming acceleration of roof & window refurbishment as well as policy scenarios that only looked at the faster refurbishment of either roofs or windows.

The policy measures needed to achieve these scenarios are twofold: first, policy instruments to ensure cost optimal retrofitting, and second, policies to accelerate the retrofitting activity. Concerning the cost optimal retrofitting of roofs and windows, minimum performance requirements could be applied (see Section 3.2). As said before, minimum performance requirements could be defined within e.g. the framework of the EuP Directive or the EPBD. On top of minimum performance requirements, some types of financial incentives or even obligations would be needed to ensure that the building element refurbishment cycles are accelerated (e.g. obligations to retrofit roofs within a specific period of time).

The energy savings of faster replacement of non cost optimal roofs and windows (in addition to cost optimal renovation and refurbishment during the natural replacement cycles) are considerable. Concerning the base case (following the EPBD recast), the energy savings for space heating are about 110 PJ higher which is approximately 45 % of the savings in the EPBD recast scenario (Table 5).

Total energy use of households can be reduced by 4.5 % to 6.4 % compared to the reference (3.3 % to 4.2 % in the base case). Compared to the cost optimal renovation & refurbishment without acceleration, the reductions are only slightly higher (see Section 3.2). The national GHG emissions can be reduced by 5.4 to 21.3 Mt CO_2-equivalents (about 1.1 % to 3.2 % of total emissions, depending on country). The GHG emission reduction potential is thus about between 27 % and 37 % higher than in the base case and about 10 % higher than without faster roof and window replacement.

Table 5 Average annual energy and GHG emission savings for renovation & refurbishment at cost optimal level and faster roof & window replacement

Country	Energy savings of households			GHG emission savings by households			Total national GHG emission savings	
	PJ	% of final energy use for space heating	% of total final energy use a)	Mt CO_2-eq.	% of space heating b)	% of total c)	Mt CO_2-eq. d)	% of total national GHG emissions
Germany	225.1	10.9	6.0	10.7	10.9	4.9	21.3	2.2
Spain	62.4	11.5	6.4	2.6	11.5	5.2	7.0	1.1
Poland	55.6	8.1	4.5	2.0	8.1	3.6	5.4	3.2

a) Including electricity; b) Including only GHG emissions from boilers in households (e.g. gas, heating oil) and excluding emissions from electricity production; c) Including all upstream emissions due to the production and provision of electricity, district heat, and other fuels; d) Including also emission reductions due to changes in economic activity and feedback loops between the sectors of the economy

The acceleration of the retrofitting increases dramatically the investment needs during the acceleration phase. After the acceleration, a considerable drop in investment occurs for ten years. When the retrofitted building elements reach their end of life, they have to be retrofitted again with increased additional investment needs. The acceleration of the retrofitting of building elements decreases energy demand and energy costs. However, the net costs are driven by the retrofitting cycles. In Figure 3, the additional investment needs and the energy costs are shown for the cost optimal renovation & refurbishment with an accelerated replacement of roofs & windows as an example for Germany.

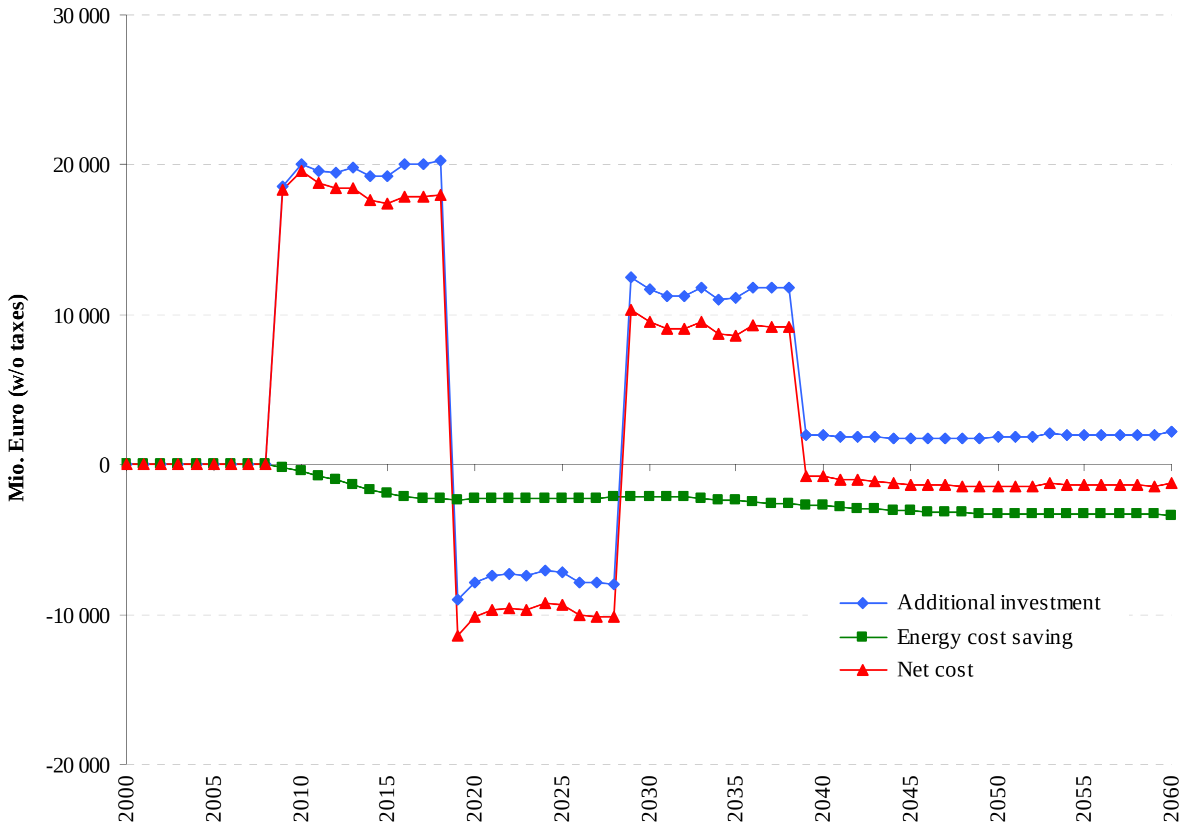

Figure 3 **Additional investment, energy cost savings and net costs for cost optimal renovation & refurbishment & faster roof and window replacement in Germany**

Compared to the total investments of the economy, the additional investment needs are quite high in this scenario in the period of accelerated replacement. The investment can be up to about 10 % higher than in the base case. Also, in the ten years following the acceleration of the retrofitting, a drop in investment occurs that can reach up to about -3 % compared to the base case. In general, the same applies for the other policy scenarios that include a faster replacement of roofs and windows. If only windows or roofs are replaced, the additional investment needs are lower (about 5 % to 6 % higher than the base case in the acceleration phase). A major impact on the economy thus can be expected. In addition, the changes in additional investment between the acceleration period and the subsequent period are substantial which implies large adjustments in the affected sectors of the economy (e.g. in the construction sector). Compared to the more balanced scenario of cost optimal renovation & refurbishment (see Section 3.2) which does not imply acceleration, the changes in investment are notably higher. Some economy sectors thus will also be influenced heavily by this policy measure (see Section 3.4). However, concerning the energy savings, no abrupt changes occur, like it is the case for the investment needs. The overall energy cost savings can reach up to about 15 % in 2060 - depending on country and year.

The socio-economic impacts of faster roof and window refurbishment show a broad range – mainly due to the major changes in additional investment (Table 6). In general, the impacts on value added, employment, and compensation of employees are positive for almost all financing options. Welfare is increased for all options in Spain and decreased for all options in Germany. The range of the average socio-economic effects of faster replacement of building elements is greater than in the non-accelerated scenarios. Still, the relative impacts are small (up to a maximum of 0.4 %). However, for individual years, the variations can be greater. For example, the impacts on value added can range from -0.6 % to 1.4 % and the impacts on employment can vary between -1.2 % and 0.8 % depending on year and country.

The best way of financing the accelerated retrofitting of roofs and windows in terms of socio-economic impacts would be via a shift of investment implying less investment in non-construction related sectors of the economy.[10] The energy cost savings of households should be spent on other consumption items (non-energy related goods). Then, the socio-economic impacts are – on average – positive in all countries and for all indicators except for welfare (for welfare, this financing scheme still leads to the best results, i.e. lowest reduction of welfare). If the investment is financed in the same way but households save the money and give it to a bank, the results for the socio-economic impacts are slightly worse but still positive for the majority the indicators. The same applies when the investment is made by households while reducing their expenditure on consumption items. A financing by the government leads to a less favourable result as it is the case for the non-accelerated cost optimal renovation and refurbishment (see Section 3.2).

The net costs (the additional expenditure for refurbishment or renovation minus the saved energy costs) for households including taxes are positive. For the years 2000 to 2060, they amount to approximately 308 700 Mio. Euro in the three countries. On average, this corresponds to annual additional costs of saving of about 5 060 Mio. Euro.

Table 6 Results of the socio-economic assessment for cost optimal renovation & refurbishment and faster roof & window replacement (average from 2000 to 2060)

Indicator	Unit	Germany	Spain	Poland
Value added	Mio. Euro/a	-1 100 to 1 236[a)]	115 to 451	-113 to 41
	%	-0.06 to 0.07	0.03 to 0.11	-0.12 to 0.04
Employment	1000 employees/a	-32 to 36	33 to 85	-13 to 3
	%	-0.09 to 0.10	0.08 to 0.20	-0.20 to 0.05
Compensation of employees	Mio. Euro/a	-1 397 to 418	49 to 221	-118 to 17
	%	-0.13 to 0.04	0.02 to 0.11	-0.24 to 0.03
Tax revenue	Mio. Euro/a	-175 to 177	-85 to 69	-25 to 6
	%	-0.31 to 0.31	-0.30 to 0.24	-0.42 to 0.11
Welfare[b)]	Mio. Euro/a	-4 164 to -2 095	517 to 862	-114 to 56
	%	-0.26 to -0.13	0.09 to 0.16	-0.08 to 0.04
Net costs	Mio. Euro	222 397	27 626	58 361

a) The results are the bandwidth of the different financing options of the policy; b) Welfare is measured by the net effects on available budget. If, for example, the energy cost savings exceed the additional expenditure, a positive welfare effect is assumed. Also indirect effects due to the recycling of tax revenue and the compensation of employees are taken into account.

When we try to distinguish the respective importance of roof refurbishment and window refurbishment, we can first compare the additional investment costs and the energy savings for each of the building element. Concerning the additional investment, the results show that, in general, the

[10] As mentioned before, some negative effects of the shift of investment is not captured by the model (e.g. impacts on the production base).

additional investment for roof refurbishment is slightly lower compared to window refurbishment (between 45 % and 49 % on average). The energy savings can not be attributed to a single measure, though.[11] For windows, the improvement potential (in terms of U-values) in Spain is higher than in Germany and Poland (see Section 5.3.2). The calculated energy savings per m^2 living area show on average higher reductions for window refurbishment than for roof refurbishment, especially for multi-family and high-rise buildings (see Section 5.3.2). The difference is more pronounced in Spain than in the other countries due to differences in e.g. climate, or building geometry. To conclude, the additional investment needs are lower for roof refurbishment than for window refurbishment, but so are the energy cost savings. The cost-benefit (net costs) maybe more in favour of window refurbishment in Spain, while in Germany and Poland, there might be no clear preference.

In this study, the environmental and socio-economic impacts of accelerating only the refurbishment of roofs and windows respectively on the whole economy were assessed, too (see Sections 9.3.6 and 9.3.7). The results of these policy scenarios confirm that the total greenhouse gas emission savings for the economy are lower for an accelerated refurbishment of roofs than for the acceleration of window refurbishment (with the differences more pronounced in Spain). Also the welfare impacts are more in favour of window refurbishment than for roof refurbishment.

The accelerated renewal of exterior wall insulation has not been considered in this study but might offer additional potential for energy and GHG emission savings. However, the same socio-economic drawbacks than in the case of faster replacement of roofs and windows should occur.

3.4 Impacts on individual sectors of the economy

The policy scenarios analysed showed little effects on the whole economy, in general. However, single sectors can be affected heavily. The ten most affected sectors of the economy in Germany are displayed in Table 7 for some selected policy scenarios.

Table 7 Effects on sectoral output of the ten most affected economy sectors in Germany according to scenario

Sector	Sector type	Base case (EPBD recast)	Cost optimal renovation & refurbishment	Base case & faster roof and window retrofitting
Products of forestry and logging	E[a)]	-2.27 to 0.05[b)]	-2.27 to 0.45	-3.50 to 4.12
Coal, lignite & peat	E	-5.23 to 0.00	-5.23 to 0.03	-5.24 to 0.00
Crude petroleum and natural gas	E	-0.69 to 0.00	n.a.	n.a.
Other mining and quarrying products	C	0.00 to 1.07	0.00 to 1.24	-3.12 to 9.96
Wood and products of wood	C	0.00 to 1.48	0.00 to 1.70	-4.20 to 13.52
Coke, refined petroleum products and nuclear fuels	E	-2.31 to 0.00	-2.31 to 0.02	-2.31 to 0.00
Other non-metallic mineral products	C	0.00 to 0.89	0.00 to 1.01	-2.51 to 8.06
Medical, precision & optical instruments	I	n.a.[c)]	-0.79 to 0.00	n.a.
Office machinery and computers	I	n.a.	n.a.	-6.46 to 2.03
Electrical energy, gas, steam and hot water	E	-4.89 to 0.00	-4.89 to 0.00	-4.89 to 0.00
Construction work	C	0.00 to 0.91	0.00 to 1.05	-2.65 to 8.46
Computer and related services	I	-1.08 to 0.00	-1.27 to 0.00	-10.38 to 3.27

a) E: energy-related sector, C: construction-related sector, I: investment-related sector; b) Results display the bandwidth of sectoral output for the years between 2000 and 2060; c) n.a.: not one of the ten most affected sectors

[11] The building stock model does not allow calculating the energy savings due to each single measure directly.

In general, the energy-related sectors (e.g. crude petroleum and natural gas; electrical energy, gas, steam and hot water) face a reduction in demand due to an increase in energy efficiency of the building stock. Reduction of demand (resulting in a reduction in sectoral output) can reach up to about -5 % in the case of the coal, lignite & peat sector. Pronounced reduction are also observed for the electrical energy & gas sector, the coke & refined petroleum products sector, and the products of forestry and logging sector (biomass for heating).

With respect to the construction-related sectors (e.g. construction work; wood and products of wood), they face a slightly increased demand in the base case (EPBD recast) and when renovation and refurbishment are carried out at cost optimal energy efficiency levels (up to about 2 %). When an acceleration of refurbishment takes place, the effects are significantly higher and can reach a maximum of about 14 %. However, during the years following the accelerated phase, a drop in demand occurs (see Figure 3). This leads to a decrease of sectoral output up to about -4 %.

A third type of sectors is the investment-related sectors which are not related to construction activities, like, for example, the office machinery & computers sector. When investment in construction is increased, these sectors face a decrease of demand due to a shift of investment, in general. When no acceleration of refurbishment takes place, the effects on these sectors can reach up to about -1 %. During acceleration, the output can be reduced by up to about -10 % while in the subsequent years, demand is notably increased (up to about 8 %).

To conclude, the energy-related sectors face a drop in demand due to an increase in energy efficiency of the residential building stock in all scenarios. The changes in output can reach up to about -5 %. When the policy aims at an acceleration of refurbishment activities, construction-related sectors are subject to great changes in demand ranging from about -4 % (during the years subsequent to the phases when acceleration takes place) to 14 % (during the phases when acceleration takes place). These sectors would have to adapt quickly to fluctuations in demand between single years.

3.5 Summary of country differences

In general, the relative reduction of energy demand for space heating is greatest in Spain, followed by Germany, and Poland for a vast majority of the policy scenarios. Consequently, also the relative GHG emission reductions due to households are greatest in Spain, with Poland showing the smallest decrease.[12]

The differences between the countries are due to the historical development of the building stock and the initial energy efficiency level of the building stock which determines renovation and refurbishment activity as well as energy efficiency improvement potential. An important parameter is also the share of different building types as the relative energy saving potential differs between building types when the energy efficiency level of walls, roofs, and windows is improved. For example, in Germany, high-rise buildings constitute only about 4 % of the residential building stock, while in Spain, 29 % of the living area belongs to high-rise buildings (19 % in Poland). In addition, the climatic conditions play a major role in explaining the country differences as they are a major factor explaining the initial energy demand for space heating.

Regarding the total national emission reduction potential, which includes not only the reduction of GHG emissions from households but also the changes in emissions in other sectors of the economy, the pattern is different. Potential relative savings are greatest for Poland, followed by Germany and

[12] Of course, due to the size of the building stock, the absolute energy savings for space heating are greatest in Germany and smallest for Poland. The same applies to the absolute GHG emission reductions which are greatest for Germany, followed by Spain, and Poland which clearly follows the size of the building stock in the three countries.

Spain. This can be explained in part by a different structure of the energy (especially electricity) sectors, and different economy structures. However, the most dominant influence is the different share of household emissions compared to rest of the economy. In general, the emission reductions in the other sectors of the economy are by far lower than the emission reduction in the households themselves. Thus, when the GHG emissions from households show a high share of total national emissions in a country, the total emission reduction will be higher compared to a country with a small share of household emissions over total national emissions.

A comparison of the socioeconomic impacts of the policy scenarios for the three countries shows that, in general, the results are better for Spain than for Germany and Poland. The differences between the countries are of course due to the structure of the economy and the factor inputs of the individual sectors of the economy. For example, the employment multipliers in the energy sectors (e.g. electricity, fuels) are quite small in Spain compared to the employment multipliers of the non energy sectors while in Germany and Poland, the difference is not so pronounced. When the energy demand of households is reduced, and the households shift their consumption to other consumption items, the employment effects will be thus greater in Spain than in the other countries. Similar effects occur for investment related spending.

To conclude, it can be stated that there exist important differences between countries which means that it is important to assess the impacts of eventual policy measures for individual countries and not at aggregate level. Energy demand and thus energy and greenhouse gas emission reduction potential depend on various variables, for example, climatic conditions, the building stock composition, the initial energy efficiency of the building stock and the historical development of the building stock. In addition, the socio-economic impacts of policy measures towards a more environmental friendly building stock are influenced by the structure and state of the economy (e.g. importance of individual economy sectors for the whole economy, labour and capital intensity of sectors).

3.6 Modelling limitations

The modelling framework applied in this study implies some weaknesses which have to be kept in mind when interpreting the results. First, some important parameters of the building stock model had to be estimated like e.g. the historical development of the building stock due to missing data. Other variables might imply uncertainties like the assumptions on future energy prices. The influence of these uncertainties has been tested by the means of sensitivity analyses and the results of this study have proven to be quite robust with respect to these types of limitations (see Section 9.4).

A second limitation of the model concerns the input-output model. The model assumes instantaneous adjustment of the economy following an external shock in final demand. This implies e.g. full labour mobility across sectors and adjustment of capital stock at zero cost which might lead to an overestimation of the effects.

The input-output model was used to assess the influence of different financing options. To this end, it was assumed that the total expenditure remains constant every year. If additional investment is needed for investments in energy efficiency, the money is taken from other items of expenditure (e.g. investment in other items is reduced, or consumer expenditure is reduced). The financing options thus only allow analysing the effects of different shifts in final demand. It has to be mentioned, that the financing options analysed can be seen as extreme cases (e.g. 100 % financing of energy efficiency investment by governments) and thus serve as to display the possible bandwidth of results. Side effects like e.g. effect of reduced investment on productivity in the subsequent years can not be assessed by the model. Also, one could imagine increases in total expenditure in one year at the expense of expenditure in following years, an option that has not been assessed with the model.

4 Main conclusions and recommendations

This study assessed various scenarios of additional policies for reducing the environmental impacts of the residential building stock in the European Union in terms of reduction of energy demand and greenhouse gas emissions. It also assessed the related socio-economic impacts. The policy scenarios included improvements of the thermal performance of building elements like e.g. windows or roofs when a regular refurbishment has to be carried out anyway as well as an accelerated replacement of building elements before they have reached the end of their life.

The study showed that it is highly recommendable to ensure that building elements are installed at cost optimal insulation level whenever they have to be renovated anyway and including minor renovations. This allows for higher energy savings (about 25 % higher than in the base case) and greenhouse gas emission savings (25 % to 30 % higher than in the base case). In addition, the scenario shows negative net costs for consumers in the long term. The socio-economic impacts are small and positive for a majority of the indicators. To achieve this potential, minimum energy performance requirements should be set close to the cost optimal level. A combination of minimum energy performance requirements for windows and roof insulation – that could be implemented under the framework of the Ecodesign Directive or other appropriate policy instruments – with ecolabel or energy label might also be considered as an option.

The acceleration of the retrofitting of building envelope elements offers a high potential for additional energy savings and GHG emission reductions. However, the cost-efficiency of these measures is low and negative socio-economic impacts are probable to occur. Significant impacts on individual sectors of the economy are to be expected (both positive and negative) which might lead to adjustment problems. For certain countries, the accelerated retrofitting of single building elements might be recommendable but this has to be studied carefully in advance and in greater detail.

It is important to mention, that the energy efficiency levels assumed at cost optimality are not very ambitious compared to low-energy and passive house standards. It has to be taken into account that these standards could be applied to new buildings (which may imply a completely different building design). Also other measures that improve energy efficiency, e.g. a replacement of the heating systems (more efficient boilers), the insulation of floors and interior walls are not taken into account in this study. This was also confirmed by the sensitivity analysis performed on the impacts of additional installation of new sealings which reduces ventilation losses. This measure offers significant potential for energy and GHG emission reductions at very low and even negative net cost.

The analysis showed that it is very important to tune the financing scheme and the respective policy measure. It seems that for a majority of the policy options, in general, the best financing scheme with respect to value added, employment, or welfare would be to keep total household budget and total investment constant.[13]

Also, the timing of the measure is important and depends very much on both the historical building stock development as this determines the renovation & refurbishment activity and the national legislation in place. When new policy measures will be proposed, this has to be taken into account when it comes to the actual organisation and definition of the respective policy measure.

In this study, the building stock was represented by generic building type models. Thus, the conclusions do not allow to infer any recommendations for individual buildings as they can deviate in

[13] This would mean that households spend the energy costs savings on other consumption items. The additional investment costs for renovation and refurbishment would be covered by a shift of investment.

important variables from our generic model types (e.g. current insulation level and orientation of the building, volume:envelope ratio, heating system, microclimate). A detailed energy analysis should thus be performed in order to derive the appropriate measures for a specific building.

The study demonstrates the advantage of not restricting the analysis of the impacts of policy measures to households (energy demand of households and the related greenhouse gas emissions, net costs for households) but also to take into account the economy-wide impacts. For example, a policy instrument with positive results for households is not necessarily also beneficial for the whole economy and vice versa. The assessment of the feedback and rebound effects within the economy is important to get the full picture and to understand all the implications of a policy measures.

Part B: Full report

5 Building stock model

The development of the building stock of each of the three countries was modelled for six different building types from 1900 to 2100 (see Section 5.1). This also includes construction and demolition activity. In addition, the building stock model allows us to quantify the renovation and refurbishment (major renovation of buildings and/or retrofitting of individual building elements like e.g. roofs or windows) of the building stock (Section 5.2). Finally, the building stock model serves to calculate the energy demand due to space heating of the building stock (Section 5.3).

5.1 Building stock development

To model the building stock of each country, six different building types were defined using information from the IMPRO-Building project which refers to the year 2006 [Nemry et al. 2008]:

- SI_HIST Single-family, historical;
- MF_HIST Multi-family, historical;
- HR_HIST High-rise, historical;
- SI_NEW Single-family, new;
- MF_NEW Multi-family, new;
- HR_NEW High-rise, new.

The historical building types were defined as a weighted average building type over all "existing" IMPRO-Building types. Likewise, the new building types were defined as a weighted average building type over all "new" IMPRO-Building types [Nemry et al. 2008]. The historical building types were used to model the building stock from 1900 to 2006. From 2007, the building stock is composed of both historical and new building types. Table 8 shows as an example the IMPRO-Building data for Germany for the year 2006.

Table 8 Building type data from IMPRO-Building for Germany in 2006

	SI_HIST	SI_NEW	MF_HIST	MF_NEW	HR_HIST	HR_NEW
Number of dwellings	18 672 000	218 430	18 672 000	232 677	1 556 000	23 743
Number of buildings	12 448 000	145 620	1 146 162	14 541	31 120	475
Building stock [Mio. m^2 living area]	1 674	21	1 675	21	140	2
Occupants	41 078 400	480 546	41 078 453	511 843	3 423 200	52 250
Density [m^2 living area/occupant]	40.8	43.7	40.8	41.0	40.9	40.2
Occupancy [occupants/building]	3.3	3.3	35.8	35.2	110.0	110.0
Dwelling size [m^2 living area/dwelling]	89.7	96.1	89.7	90.3	90.0	88.4
Share of building stock [%]	47.4	0.6	47.4	0.6	4.0	0.1

The historical building stock development was derived from national statistics, or Eurostat data. The shares of the three historical building types were derived according to the shares from IMPRO-Building for 2006 [Nemry et al. 2008]. For the period before actual time series data was available, it was assumed that the building stock in 1900 was 25 % (10 % in case of HR) of the stock of the earliest year for that time series data was available. For Germany, time series data was available from 1986 to

2006 [Destatis 2007]. For 1900 to 1985, the data was thus interpolated. The Polish statistical office provided data from 2002 to 2006 [GUS 2007]. Thus, the data until 2001 was interpolated here. In Spain, data for construction activity could be retrieved [INE 2009]. The time series ranges back to 1990. Demolition was calculated assuming construction being five times the demolition activity (see below). From the building stock in 2006 from [Nemry et al. 2008], the net construction and the building stock for 1990 to 2006 could be calculated. Data from 1900 to 1989 was interpolated.

From 2007, projections from PRIMES were used [Capros et al. 2008]. Country-specific information on annual increase of the number of dwellings for 2007-2010, 2020-2020, and 2020-2030 was available. In order to avoid 'artificial' breaks in 2010/11, 2020/21, and 2030/31, the annual increase of the number of dwellings was assumed for all years as for 2020-2030 (0.1 % in Germany, 0.7 % in Poland, and 0.5 % in Spain). The annual increase of the size of households (m^2) was assumed to be equal for all countries (0.9 %) because there was no country specific data available [Capros et al. 2008].

From the annual stock data S_t, the net construction NC_t was derived as the difference between the stock in the present and the previous year: $NC_{t-1} = S_t - S_{t-1}$. For gross construction and demolition, it was assumed that gross construction C is five times as high as demolition DEM.[14] Thus, gross construction GC and demolition DEM of the total building stock could be calculated with $DEM_t = NC_t/5$ and $GC_t = DEM_t*(5+1)$. Figure 4 shows the results for the construction and demolition activity in Germany from 1900 to 2100. From 1900 to 1986 (in the case of Germany), a linear growth of the building stock was assumed.

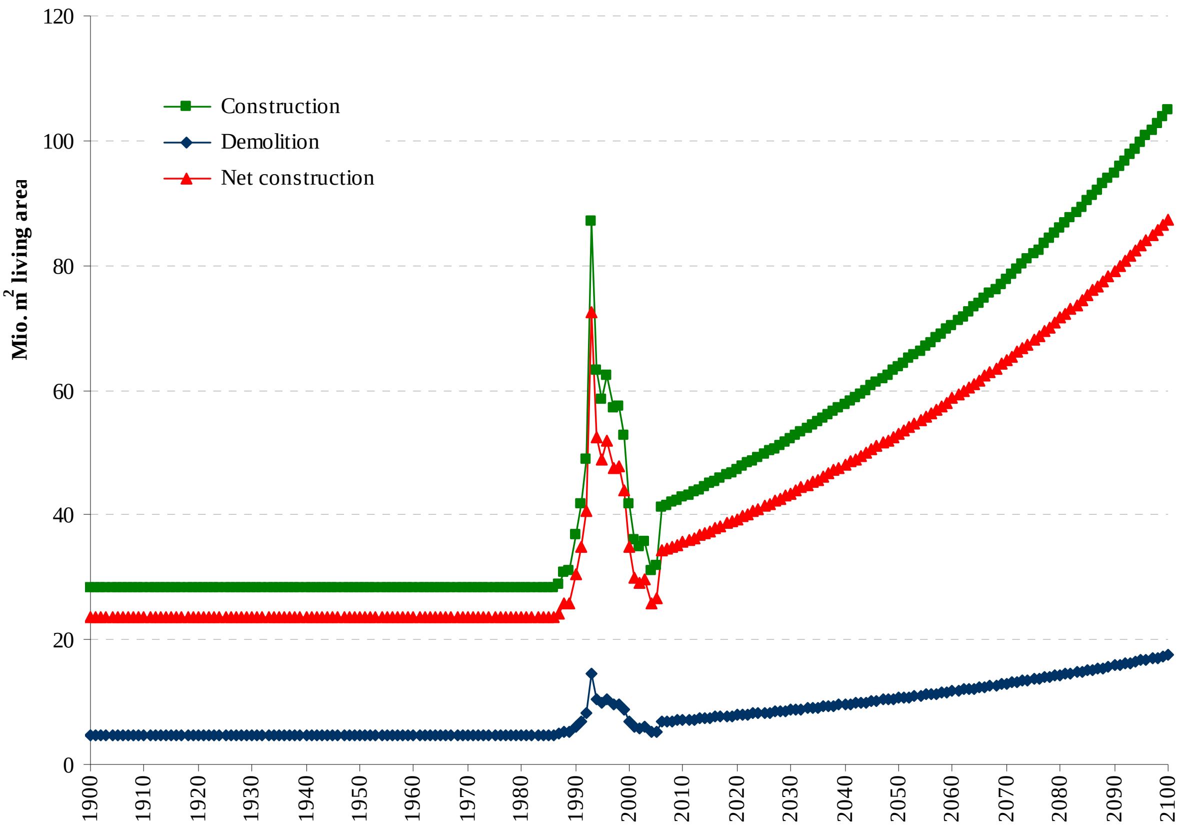

Figure 4 Construction and demolition activity in Germany from 1900 to 2100

[14] The influence of this assumption on the results will later be explored by means of sensitivity analysis.

The actual time series data from national statistics from 1986 to 2006 shows a clear peak for the mid 90s which might be attributed to the German reunification and subsequent increase in building activity in Eastern Germany. Construction activity drops again to the level before this peak in 2005. In 2006, the construction activity again shows a remarkable increase compared to 2005. From 2006, we can see the exponential increase due to the PRIMES assumptions.

Total stock, construction and demolition were then distributed among the six different building types. For the building stock from 1900 to 2006, stock, construction, and demolition were distributed according to the shares from IMPRO-Building for 2006 [Nemry et al. 2008]. From 2007, it was assumed, that only new buildings are built (according to the shares from IMPRO-Building for 2006). Demolition was calculated according to the respective share of stock (which means, that demolition is not affected by age or type of building).

Figure 5 shows the resulting building stock development in Germany from 1900 to 2100 according to the six building types. We again see the linear increase of the building stock from 1900 to 1986 (when actual time series data is available). The building stock then increases faster from 1986 to 2006, with a peak between the mid 90s and 2000. From 2006, the building stock is assumed to increase exponential.

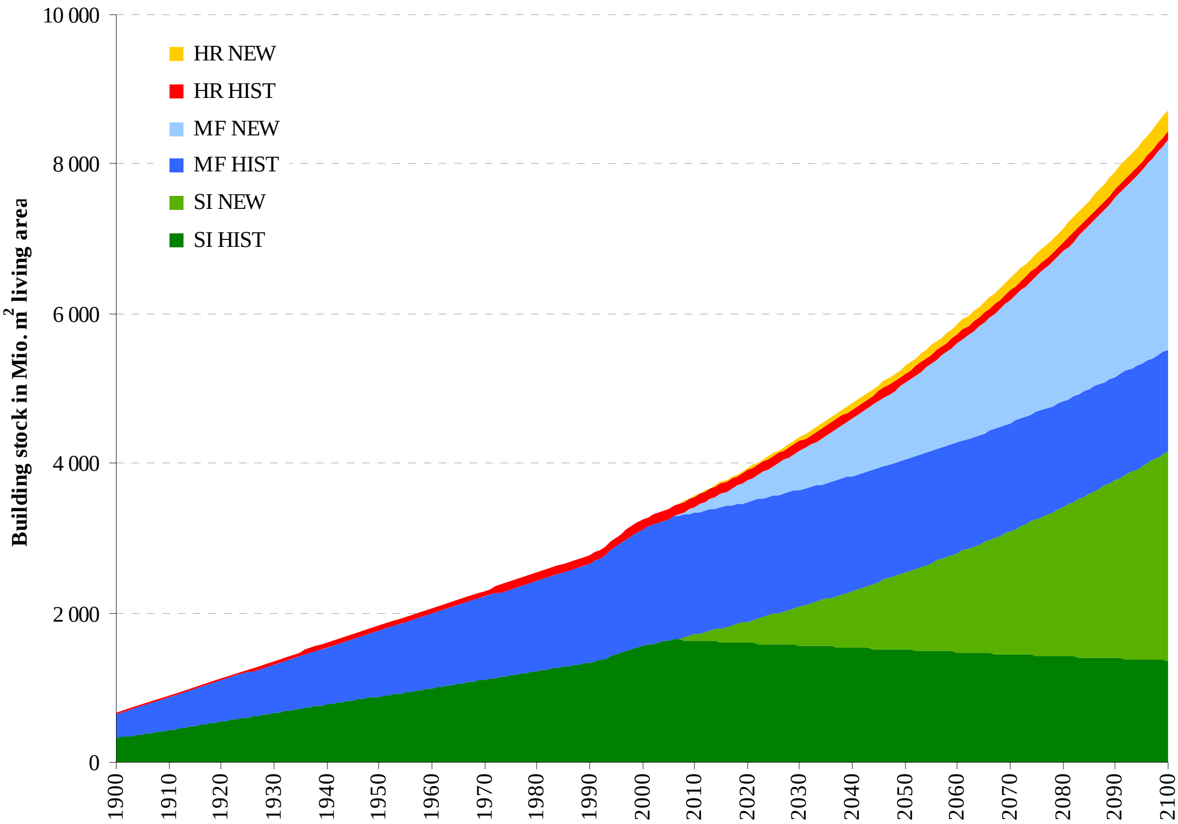

Figure 5 Building stock in Germany from 1900 to 2100 according to the six building types

From Figure 5, it can be seen that in the year 2100, still a considerable share of historical building types exist (about 30 %). Single-family and multi-family houses account for 95 % to 98 % of the total building stock.

5.2 Refurbishment cycles

5.2.1 Major renovation

Major renovation in this study was defined as the renovation of exterior walls, roofs, and windows. To model the major renovation of buildings, it was assumed that major renovation takes place every 40 years [Nemry et al. 2008]. Four different energy efficiency levels were assumed (see Section 5.3). These energy efficiency levels allow us to model the progress of energy efficiency of the building stock over time either due to the construction of more energy efficient buildings or due to the renovation or retrofitting of buildings which can lead to a higher level of efficiency (e.g. additional insulation of walls or roof). When a building undergoes a major renovation, the energy efficiency level of the respective year has to be taken into account. For example, if a building is renovated in 1965 and the energy efficiency level is 1 in 1965, it is renovated to EE level 1. Construction was assumed to take place also according to EE level. For example, if a building is constructed in 1965, the building constructed ‘belongs’ to EE level 1.

Major renovation of each energy efficiency level is calculated as follows. First, a decision parameter *D* was calculated. We assume that 40 years after the last major renovation took place, it has to be decided if the building will be demolished or renovated again. The number of buildings for which a decision was calculated as: $D_t = GC_{t-40} + MRS_{t-40}$. *D* equals the number of buildings constructed 40 years before GC_{t-40} (in the same EE level) plus the number of buildings that were renovated 40 years before and stayed in the same EE level MRS_{t-40}. As we see from Figure 6, the decision increases stepwise every 40 years and it follows the building activity pattern with a lag of 40 years (see Figure 4).

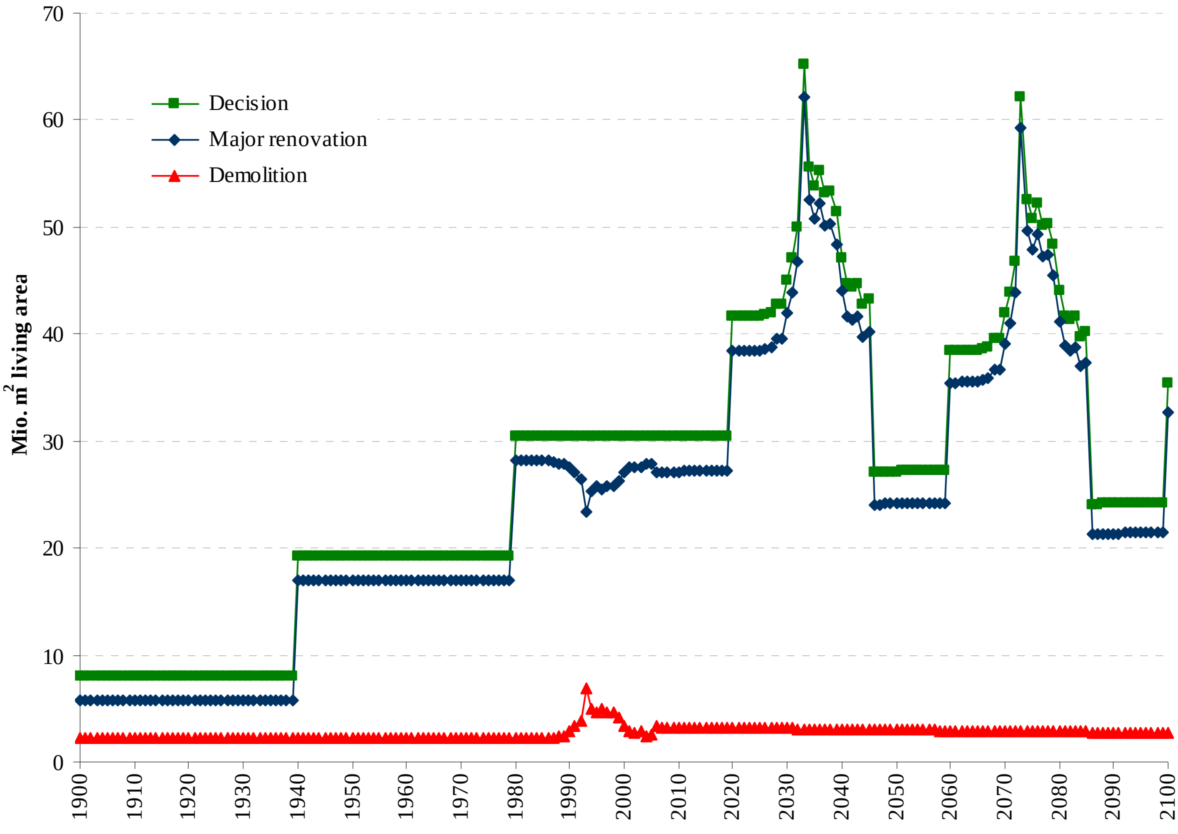

Figure 6 Building stock variables for major renovation in Germany for SI_HIST

After having calculated the number of decisions *D*, secondly, the major refurbishment *MR* is calculated as the residual $MR_t = D_t - DEM_t$. Major refurbishment is thus calculated as the share of buildings from *D* that are not demolished *DEM* (with demolition assumed as exogenous variable derived from the building stock development, see section 5.1). For the energy efficiency levels 1 to 3, in addition not only the number of buildings constructed 40 years before (in the same EE level) plus the number of buildings that were renovated 40 years before has to be taken into account but also the number of buildings that were renovated 40 years before from a lower EE level (*MRL*). *D* thus can be calculated as: $D_t = C_{t-40} + MRS_{t-40} + MRL_{t-40}$. For example, for EE 2, this includes buildings of EE level 0 and EE level 1 that were renovated to EE level 2 40 years before. For the years 1900 to 1940 (when no data is available to calculate *D* from previous years) an assumption on *D* has to be made.

It was estimated that *D* is constant for all the years 1900 to 1940 and that it equals the stock in 1900 divided by 40. This implies the assumption that the building stock has been constant over the last 40 years (1860 to 1900) and that the whole building stock that was built before 1900 will have been renovated in 1940.

As an example of the results, Figure 7 displays the building stock of the building type SI_HIST ('historical single-family houses') for Germany according to energy efficiency levels for the reference scenario.

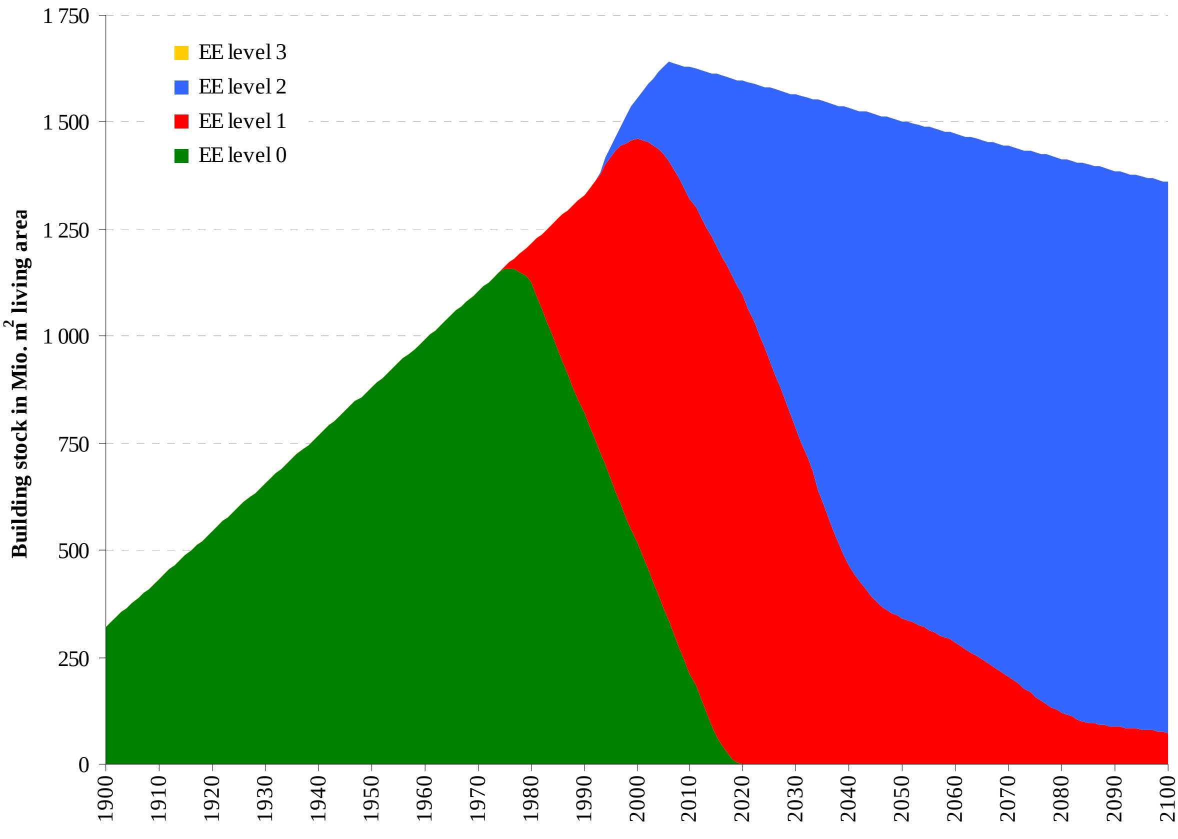

Figure 7 Building stock in Germany from 1900 to 2100 for SI_HIST according to EE level (reference scenario)

As we can see from Figure 7, the EE level 0 is present in the building stock until 2020. The next EE level 1 kicks in from 1974. EE level 2 appears in 1991. In the reference scenario, it was assumed that EE level 3 never occurs (see Section 5.3).

5.2.2 Building element refurbishment

Besides the major renovation activities, also the refurbishment of single building elements (only windows and roofs, not walls) was taken into account. As in the case of major renovation, four different energy efficiency levels were assumed. The refurbishment activities were calculated in a similar way then the major renovation. The refurbishment cycle was assumed to be 20 years. The building element refurbishment was calculated for each building type and each major renovation energy efficiency level separately. In general, it was assumed that the EE level of building element can never be lower than the major renovation EE level.

In general, building elements are refurbished (*RR* and *WR*, respectively) when the building was erected 20 years ago or the building was subject to a major renovation 20 years ago (and stayed in the same EE level). In addition, it has to be accounted for these buildings that are subject to major renovation or demolition (which sum to *D*) in the same year as it was assumed that if major renovation takes place, the single building elements will not be refurbished at the same time. The same applies for demolition, of course. Building element refurbishment can thus be calculated as: $RR_t = GC_{t-20} + MRS_{t-20} - D_t$. For the EE levels 1 to 3, we have also to take into account the buildings that 'come' from lower EE levels. Thus, MRL_{t-20} has to be added in these cases (see Section 5.2.1).

As it is the case for major renovations, an assumption has to be made for the years 1900 to 1920 (when no data is available to calculate *GC* and *MRS* from previous years). It was assumed that building element refurbishment equals *D* for these years.

The building stock can now be disaggregated into combinations of different EE levels. We use the following nomenclature: MR-RR-WR (EE level of major renovation status, EE level of roof refurbishment status, and EE level of window refurbishment status). In theory, there are 28 possible combinations of EE levels (Table 9).

Table 9 Possible EE levels for major renovation and building elements and combinations in the reference scenario

EE level major renovation	EE level roof	EE level window	EE level combination
0	0	0	0-0-0
	1	1	0-1-1
	2	2	0-2-2
	3	3	0-3-3
1	1	1	1-1-1
	2	2	1-2-2
	3	3	1-3-3
2	2	2	2-2-2
	3	3	2-3-3
3	3	3	3-3-3

Due to the assumption that window and roof refurbishment have the same refurbishment cycles, the number of possible combinations is reduced to only 10 possible combinations in the reference scenario. In fact, even of these 10 combinations, not all occur in practice (compare Figure 9). For the single policy scenarios described in Section 8, more combinations than 10 are possible but the maximum number of 30 combinations is never reached.

5.3 Energy efficiency levels

5.3.1 Energy efficiency levels in the reference scenario

The energy efficiency levels applied to new construction of renovation is shown in Figure 8 for the reference scenario. It was assumed that until the year 1973 (first oil price shock), only energy efficiency level 0 existed (Table 10).

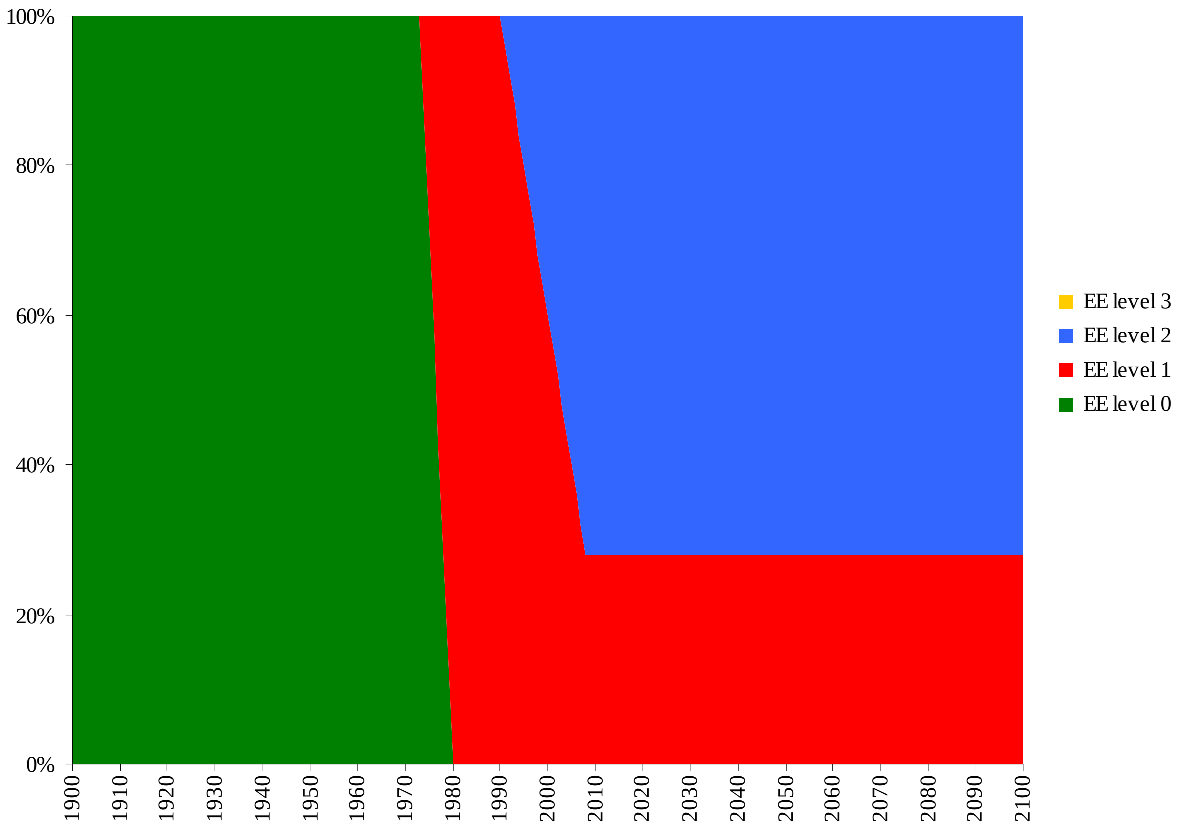

Figure 8 Energy efficiency levels of new construction or renovation (reference scenario) from 1900 to 2100

Starting from 1974, energy efficiency level 1 slowly paces in. From 1974 to 1979 (second oil price shock), both energy efficiency level 0 and energy efficiency level 1 occurred (Figure 8). From 1980 to 1990, it was assumed that only energy efficiency level 1 was present, while from 1991 energy efficiency level 2 starts to phase in. It was assumed that energy efficiency level 1 still shows a substantial share in year 2005 (40 %).

While the energy efficiency level 2 phases out in 2015, the energy efficiency level 3 which was defined as the cost optimal energy efficiency level starts being available from 2014.

From 2008, the EE level distribution is kept constant in the reference scenario. The shares of EE level 2 and level 3 are 28 % and 72 %, respectively. In the reference scenario, EE level 3 never shows up. The EE level distribution for the different policy scenarios will be detailed under the respective scenario description in Section 8.

Figure 9 shows the building stock according to EE level combinations in Germany for the reference scenario as an example. Up to 1993, the building stock is dominated by major renovation EE level 0, while EE level 1 is most important between 1994 and 2027. From 2028, EE level 2 accounts for the majority of the building stock in Germany in the reference scenario. EE level 0 will be totally phased out in 2020 in Germany in this reference scenario.

Table 10 Overview over the energy efficiency level selection and time span of application

EE level	Principle	Time span of application	Years of dominance
0	No insulation, single pane windows	Until 1979 (second oil price shock)	Until 1973 (first oil price shock)
1	After first oil shock, simple double pane windows	Until 2006 (entry in force of EPBD)	From 1974 to 2002
2	Current most common practice[a)]	1991-2016	From 2003 to 2015
3	Cost optimal[b)]	From 2014	From 2015

a) reflects the current national minimum performance requirements according to [ECOFYS 2005a, ECOFYS 2005b]; b) advanced standard retrofit package according to [ECOFYS 2005a, ECOFYS 2005b]

In the reference scenario depicted, still a considerable share of the building stock remains within major renovation EE level 1. This is due to the assumption that the shares of EE level 1 and EE level 2 will remain constant from 2008 (28 %, and 72 %, respectively). Thus, 28 % of the new buildings erected after 2008 will be build according to the energy efficiency level 1.

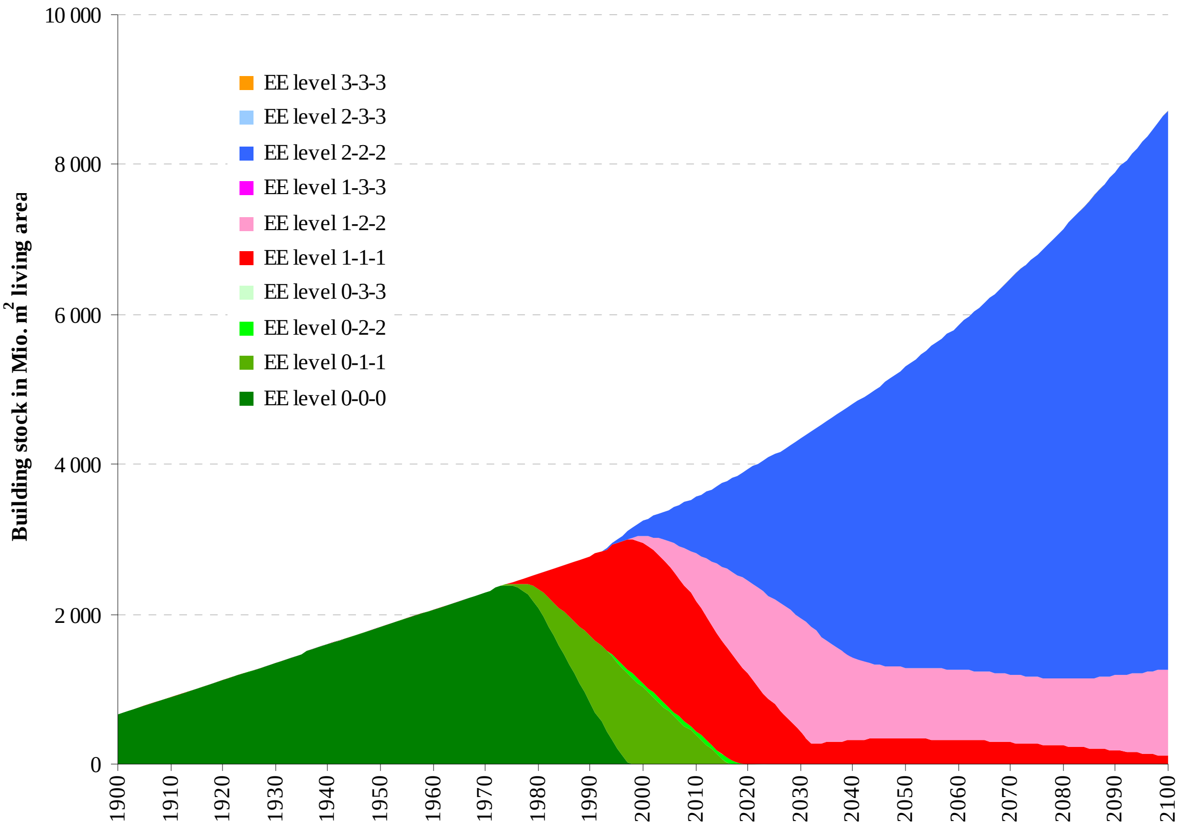

Figure 9 Building stock in Germany from 1900 to 2100 according to EE level combinations

For Poland and Spain, the picture looks quite similar. In order not to needlessly repeating the results, we do not display the respective figures for these two countries here.

5.3.2 Energy efficiency levels and translation into EPIQR (U-values)

The disaggregation of the building stock according to energy efficiency level combinations (Figure 9) was used to calculate the energy demand of the building stock for space heating using EPIQR [EPIQR 1996]. The methodology applied for these calculations was the same than in the IMPRO-Building project [Nemry et al. 2008]. As we defined six aggregated building types (see Section 5.1), also the energy demand was calculated as a weighted average of the energy demand of the individual building types from IMPRO-Building. The energy demand was calculated for each country and EE level combination.

For the EPIQR calculations, the energy efficiency levels had to be translated into U-values (windows) or thickness of insulation (cm additional insulation). This was achieved by using literature information (e.g. [ECOFYS 2005a]), and common calculation tools to translate U-values into insulation thickness.[15] Additional roof insulation in EPIQR ranges from 0 cm to 20 cm, additional wall insulation (which is applied when major renovation takes place) from 0 cm to 16 cm. The U-values for windows range from the existing U-value (which depends on the individual building type) to 1.2. In EPIQR, insulation levels can not be introduced in a continuous level (e.g. from 0 cm to 20 cm) but are only available for some steps (e.g. 0 cm, 2 cm, 6 cm, 12 cm, 16 cm, and 20 cm). The EPIQR values that were used were those that were closest to the calculated insulation levels (Table 11).

Table 11 EPIQR values corresponding to EE levels for the three countries

Country	EE level	Window refurbishment	Roof refurbishment	Wall refurbishment
Germany	0	Existing	No additional insulation	No additional insulation
	1	U-value 2.5	6 cm additional insulation	4 cm additional insulation
	2	U-value 1.6	16 cm additional insulation	8 cm additional insulation
	3	U-value 1.2	20 cm additional insulation	16 cm additional insulation
Spain	0	Existing	No additional insulation	No additional insulation
	1	U-value 3.5	3 cm additional insulation	3 cm additional insulation
	2	U-value 2.5	6 cm additional insulation	6 cm additional insulation
	3	U-value 1.9	8 cm additional insulation	8 cm additional insulation
Poland	0	Existing	No additional insulation	No additional insulation
	1	U-value 2.5	6 cm additional insulation	4 cm additional insulation
	2	U-value 1.9	16 cm additional insulation	10 cm additional insulation
	3	U-value 1.6	26 cm additional insulation	16 cm additional insulation

Data sources: [ECOFYS 2005a, ECOFYS 2005b, EPIQR 1996, Nemry et al. 2008, Plewako et al. 2007, own assumptions]

The annual energy demand for space heating per square meter living area for the six aggregated building types according to the ten main energy efficiency level combinations (Table 9) is displayed in Figure 10 for Germany as an example. Major energy demand reductions occur in the lower EE levels mainly. The differences between higher EE levels (e.g. levels 1 and 2 and levels 2 and 3) are comparably small. Improvement potentials are higher for the historical building types than for new building types (which already show higher insulation levels).

In general, the energy savings amount to about 30 % to 56 % when moving from 0-0-0 to the 1-1-1 level combination, and to 43 % to 68 % for 2-2-2 compared to 0-0-0. The savings in the case of 3-3-3 range from 51 % to 74 %. Additional savings are thus quite low between EE level 2 and EE level 3. This holds also true for the other two countries analysed: for Poland, the energy savings range from 28 % to 56 % for 0-0-0. These values are the same than for Germany because the same insulation

[15] See for example: http://www.energiesparhaus.at/denkwerkstatt/uwert.htm.

levels were assumed for EE levels 0 and 1 in Germany and Poland. For EE level 2-2-2, the reductions range from 39 % to 64 % which is a bit lower compared to the savings in Germany due to lower level of insulation. Finally, for 3-3-3, the energy savings are about 40 % to 68 % which is again lower due to lower level of insulation.

In warm climates, the picture is similar to Poland. In Spain, the energy savings range from 28 % to 53 % for 1-1-1, and around 37 % to 64 % for 2-2-2. For the EE level combination 3-3-3, between 40 % and 68 % of the energy for space heating can be saved compared to EE level combination 0-0-0.

For comparison purposes, also the energy demand of low energy and passive houses are shown in Figure 10. The low energy house compares to the KfW40-standard (40 kWh energy demand per m^2 and year), the passive house standard means 15 kWh per m^2 and year.[16] The defined energy efficiency levels are still far from ‘best practise’ building construction. For high-rise buildings, low energy house standards can be achieved in EE level 3 but energy demand is around 2.5 times higher compared to passive house standards. For single-family and multi-family houses, the energy demand for the EE level 3 is between 1.5 to 4 times higher than the energy demand of a low energy house. For the passive house standard, the EE level 3 buildings need still about 4 to 8 times more energy per square meter.

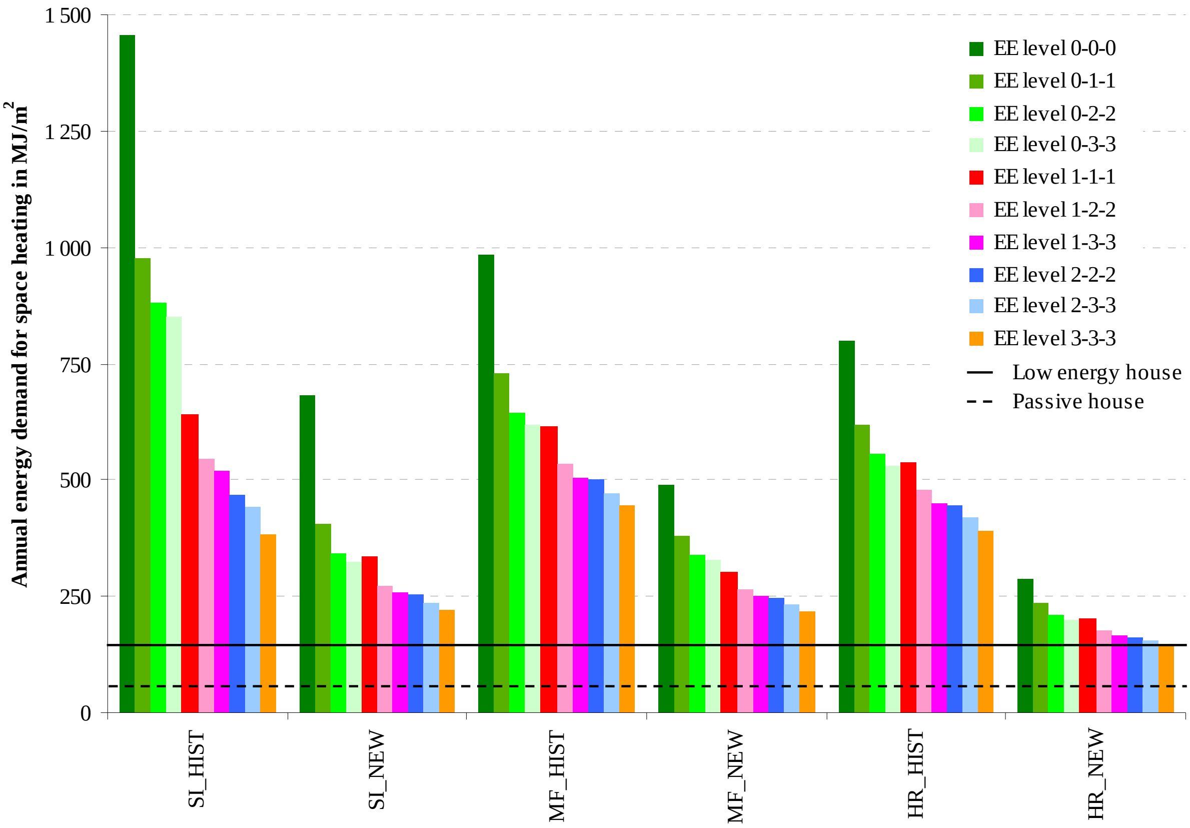

Figure 10 Energy demand for space heating according to EE levels for Germany for the individual building types

The comparison with low energy and passive house standards show that the cost-efficient EE levels are not too ambitious but one has to take into account that these standards are applied to new buildings (which may imply a completely different building design). Also other measures that improve energy efficiency, e.g. a replacement of the heating systems (more efficient boilers) are not taken into account in this study.

[16] See: http://www.kfw-foerderbank.de/EN_Home/Programmes_for_residential_buildings/KfWCO2Redu.jsp.

6 Cost and energy data

To calculate the associated costs of the individual policy scenarios, cost data for the renovation and refurbishment measures according to energy efficiency levels has to be defined (Section 6.1). In addition, data on the energy mix for space heating and the associated energy costs according to energy carrier are needed to calculate the energy costs and the cost savings due to a reduction in energy demand of the policy scenarios (Section 6.2). In order to transfer the results to the input-output framework for calculating the economy-wide impacts, the cost data is needed excluding taxes like VAT and other taxes like energy tax (Section 7.2).

6.1 Renovation, refurbishment and construction cost

Cost data was retrieved and defined for Germany first. Country specific building costs were derived by applying the building cost index from [BKI 2009]. This country-specific building cost index includes an analysis of 1 200 projects. The cost index for Germany is 1.0, while for Poland, a value of 0.483 applies. The cost index for Spain is 0.815 [BKI 2009]. The building cost index was applied only to net price and mounting while VAT and other taxes were defined for each individual country separately.

6.1.1 Window refurbishment

Cost data for window refurbishment can be derived from [VFF 2007] for Germany. Dismounting and disposal of the old windows is not included (Table 12).

Table 12 Standard costs of windows in Euro for Germany

Frame	Net price	Mounting	VAT	Total
Plastic	210.00	104.00	59.66	373.66
Wood	260.00	104.00	69.16	433.16
Wood-aluminium	360.00	104.00	88.16	552.16
Aluminium	450.00	104.00	105.26	659.26

The standard costs include the cost of installation (without demounting and disposal of the old window) and the VAT (19 %)

From Ecofys, the investment cost for window replacement is available according to regional zones [ECOFYS 2005a]. Windows can be replaced to improve energy efficiency or can be replaced as a coupled measure.[17] The estimated costs are displayed in Table 13.

Also, EPIQR can be used to calculate cost data [EPIQR 1996]. For Z2_SI_001X, the replacement of windows costs 8 600 Euro per building. Assuming an average of 22 windows, the replacement cost is about 391 Euro per window (about 231 Euro per m^2).[18] Window replacement for Z2_MF_001X would cost 78 700 Euro per building which is 463 Euro per window (274 Euro per m^2). For high-rise buildings (Z1_HR_001X), the cost would amount to 209 500 Euro per building, which equals around

[17] “The replacement cost of the windows to the minimum requirements of the building regulations in the respective country are taken into account as non-energy related costs. Additional costs to meet the expert forecast for the EPB standards are treated as energy-related costs” [ECOFYS 2005a].

[18] Assuming an average window size of 1.3m x 1.3 m (1.69 m^2) according to [VFF 2007].

446 Euro per window (264 Euro per m^2). EPIQR values thus range from about 390 to 460 Euro per window.

Table 13 Investment costs for window replacement in Euro/m^2 window for Europe

Parameter	Unit	Cold zone	Moderate zone	Warm zone
U-value before retrofit	[W/m^{2}K]	3.00	3.50	4.20
U-value after retrofit	[W/m^{2}K]	1.33	1.68	2.71
Total investment costs[a)]	[Euro/m^2]	433	316	142
Additional investment[a)]	[Euro/m^2]	133	116	60

a) Including material, labour, applicable taxes as well as overheads and profits. The costs are given in equivalent value of Euro$_{2002}$

According to [Engblom 2006], the demolition and removal of old windows in office buildings costs around 13 Euro/m^2. Total replacement costs of windows is given with about 300 Euro/m^2 (U-value 2.0 W/m^{2}K) and 400 Euro/m^2 for a better performing window (triple-pane, argon, U-value 1.0 W/m^{2}K).

In Table 14, an overview over the cost data found is presented.

Table 14 Overview over window replacement costs in Euro found in the literature

Source	Cost per window	Cost per m^2	Comment
[VFF 2007]	374-660	221-390	Including VAT and mounting
[ECOFYS 2005a]	196-534	116-316	Including VAT, mounting, profits, and taxes
[EPIQR 1996]	391-463	231-274	Including VAT and mounting
[Engblom 2006]	507-676	300-400	Including VAT and mounting

To conclude, we used a combination of the available data [ECOFYS 2005a, VFF 2007] to estimate the costs for window refurbishment. For windows of EE level 0, we assumed (for Germany) a cost of approximately 200 Euro per m^2 window area. The mounting costs were estimated with 100 Euro and it was assumed that they are independent of the EE level of the window [VFF 2007]. Thus, a net cost of 70 Euro per m^2 window was assumed for EE level 0. For the next EE levels, we assumed a net price increase of 40 Euro per level. For EE level 3 it was assumed that the costs do not increase linearly but only increase by 10 Euro compared to EE level 2 (Table 15).

Table 15 Assumed window refurbishment costs in Euro/m^2 window area according to EE level

Country	EE level	Net price	Labour cost	Price w/o taxes	VAT[a)]	Total
Germany	0	70.00	100.00	170.00	32.30	202.30
	1	110.00	100.00	210.00	39.90	249.90
	2	150.00	100.00	250.00	47.50	297.50
	3	160.00	100.00	260.00	49.40	309.40
Poland	0	33.81	48.30	82.11	18.06	100.17
	1	53.13	48.30	101.43	22.31	123.74
	2	72.45	48.30	120.75	26.57	147.32
	3	77.28	48.30	125.58	27.63	153.21
Spain	0	57.05	81.50	138.55	22.17	160.72
	1	89.65	81.50	171.15	27.38	198.53
	2	122.25	81.50	203.75	32.60	236.35
	3	130.40	81.50	211.90	33.90	245.80

a) A VAT rate of 19 % has been applied to Germany. For Poland and Spain, VAT rates of 22 % and 16 %, respectively were assumed

The cost data for Poland and Spain was calculated applying the building cost index according to [BKI 2009] to the net price and mounting. VAT rates were assumed for each country accordingly.

6.1.2 Roof refurbishment

Some information on roof insulation is available from Ecofys [ECOFYS 2005a]. However, Ecofys only analyse additional insulation between rafters of pitched roofs. Thus, a coupled measure is not feasible. All the costs have to be assigned to the additional insulation and no data on conventional roof refurbishment is available. The costs are displayed in Table 16.

Table 16 Investment costs for additional roof insulation in Euro/m² for Europe

Parameter	Unit	Cold zone	Moderate zone	Warm zone
U-value before retrofit	[W/m²K]	0.50	1.50	3.40
U-value after retrofit	[W/m²K]	0.13	0.23	0.43
Investment costs[a)]	[Euro/m²]	46	25	16

a) Including material, labour, applicable taxes as well as overheads and profits. The costs are given in equivalent value of $Euro_{2002}$

EPIQR can also be used to calculate cost data. For example, for a single-family house in the central European zone, an additional roof insulation of 16 cm costs 4 480 Euro per building [EPIQR 1996]. A new roof (new roof tiles) cost about 7 710 Euro. Assuming 120 m² roof area, the costs per m² sum up to 37 and 64 Euro/m², respectively. For a multi-family house, the costs are 19 140 Euro and 32 900 Euro (about 39 and 66 Euro/m²). For high-rise buildings, the cost would amount to 22 440 Euro and 38 560 Euro per building, which equals around 50 and 86 Euro per m².

The IMPRO-Building project analysed the roof refurbishment of single-family houses in Southern Europe [Nemry et al. 2008]. The cost for conventional refurbishment ranges from 110 to 137 Euro/m² roof area, depending on the building type. For retrofit (conventional refurbishment & additional roof insulation), the costs amount to about 146 to 183 Euro/m².

The Online calculation tool Roofing Calculator gives estimates of about 113 to 151 Euro/m² for pitched roofs with tiles, depending on the roofing pitch [LA Metal Roofs 2009]. According to [Engblom 2006], the roof refurbishment costs for office buildings amount to 74 Euro/m² (U value 0.15) and 102 Euro/m² (U value 0.15). Table 17 contains an overview of the cost data found in the literature.

Table 17 Overview over roof refurbishment costs in Euro/m² found in the literature

Source	Conventional roof refurbishment	Additional roof insulation	Comment
[ECOFYS 2005a]	n.a.	25	VAT is included probably
[EPIQR 1996]	64-86	37-50	Including mounting, VAT, profits, taxes
[Nemry et al. 2008]	110-137	36-46	For Southern Europe (VAT included)
[LA Metal Roofs 2009]	113-151	n.a.	Including VAT and labour costs
[Engblom 2006]	74-102	n.a.	For office buildings (flat roof)

For Germany, we assumed a cost (net price) of 25 Euro/m² for EE level 0 according to [ECOFYS 2005a] and an increase of roof refurbishment price of 15 Euro/m² for level 1, 25 Euro/m² for EE level 2 and 30 Euro/m² for EE level 3 which follows closely the amount of additional insulation in cm applied (see Table 11). The tax share of the costs was calculated according to a VAT rate of 19 %. The labour costs were assumed to amount to 50 % of the insulation costs of the EE level 2 insulation. Table 18 summarised the estimations of the roof refurbishment costs.

Table 18 Assumed roof refurbishment costs in Euro/m² roof area according to EE level

Country	EE level	Net price	Labour cost	Price w/o taxes	VAT[a)]	Total
Germany	0	25.00	60.00	85.00	16.15	101.15
	1	30.00	60.00	90.00	17.10	107.10
	2	40.00	60.00	100.00	19.00	119.00
	3	45.00	60.00	105.00	19.95	124.95
Poland	0	12.08	28.98	41.06	9.03	50.09
	1	14.49	28.98	43.47	9.56	53.03
	2	19.32	28.98	48.30	10.63	58.93
	3	21.74	28.98	50.72	11.16	61.87
Spain	0	20.38	48.90	69.28	11.08	80.36
	1	24.45	48.90	73.35	11.74	85.09
	2	32.60	48.90	81.50	13.04	94.54
	3	36.68	48.90	85.58	13.69	99.27

a) A VAT rate of 19 % has been applied to Germany. For Poland and Spain, VAT rates of 22 % and 16 %, respectively were assumed

Data for Poland and Spain was derived by applying the building cost index according to [BKI 2009] to the net price and mounting. VAT rates were assumed for each country accordingly.

6.1.3 Major renovation

In this study, a major renovation includes the refurbishment of roof and windows. In addition, also the façade will be refurbished (see Section 5.2.1). The cost data for roof and window refurbishment has already been defined. What is missing still is the data for exterior wall refurbishment. Data from [Wetzel & Vogdt 2007] suggests that the set up costs for a thermal insulation composite system (exterior wall) in Germany costs between 70 and 90 Euro/m² (including rendering). Compared to a renewed rendering (around 57 Euro/m²), the ETICS costs about 22 Euro/m² more [Wetzel & Vogdt 2007].

We assume the costs (net price) for wall refurbishment to be 20 Euro/m² wall area for EE level 0 (Table 19). For the subsequent EE levels, we assume an increase of 0.50 Euro per cm additional insulation based on Germany values (see Table 11). Mounting cost was estimated to be 30 Euro/m². Data for Poland and Spain was calculated as in the case of window and roof refurbishment.

Table 19 Assumed wall refurbishment costs in Euro/m² wall area according to EE level

Country	EE level	Net price	Labour cost	Price w/o taxes	VAT[a)]	Total
Germany	0	20.00	30.00	50.00	9.50	59.50
	1	22.00	30.00	52.00	9.88	61.88
	2	24.00	30.00	54.00	10.26	64.26
	3	28.00	30.00	58.00	11.02	69.02
Poland	0	9.66	14.49	24.15	5.31	29.46
	1	10.63	14.49	25.12	5.53	30.65
	2	11.59	14.49	26.08	5.74	31.82
	3	13.52	14.49	28.01	6.16	34.17
Spain	0	16.30	24.45	40.75	6.52	47.27
	1	17.93	24.45	42.38	6.78	49.16
	2	19.56	24.45	44.01	7.04	51.05
	3	22.82	24.45	47.27	7.56	54.83

a) A VAT rate of 19 % has been applied to Germany. For Poland and Spain, VAT rates of 22 % and 16 %, respectively were assumed

We then have to convert the data for roof, window and wall refurbishment from Euro per m^2 building element to Euro per m^2 living area. This was done using the building stock distribution between SI, MF and HR buildings for the year 2006 (which is constant from 2006 on) and based on data concerning the building geometry (e.g. wall to window ratio, living area to wall area ratio) from [Nemry et al. 2008].

The total cost of major refurbishment is the sum of roof and window refurbishment plus wall insulation which leads to the costs summarised in Table 20.

Table 20 Assumed major renovation costs in Euro/m^2 living area according to EE level

Country	EE level	Net price	Labour cost	Price w/o taxes	VAT	Total
Germany	0	72.53	125.38	197.91	37.60	235.51
	1	91.40	125.38	216.78	41.19	257.97
	2	114.28	125.38	239.66	45.54	285.20
	3	127.62	125.38	253.00	48.07	301.07
Poland	0	34.57	59.74	94.31	20.75	115.06
	1	43.58	59.74	103.32	22.73	126.05
	2	54.50	59.74	114.24	25.13	139.37
	3	60.86	59.74	120.60	26.53	147.13
Spain	0	58.32	100.76	159.08	25.45	184.53
	1	73.52	100.76	174.28	27.88	202.16
	2	91.93	100.76	192.69	30.83	223.52
	3	102.65	100.76	203.41	32.55	235.96

6.1.4 New construction of buildings

Costs for the construction of new buildings were available from [Frech et al. 2007]. The average costs for 1 m^2 building area in 2000 were 1 254 Euro/m^2 (and 141 300 Euro per dwelling). It has to be kept in mind that this not only includes the costs per m^2 living area, but the costs for the whole dwelling (including the parts that are not used as living area). The costs per m^2 living area thus are higher than the costs per m^2 construction (see below).

We can also use gross fixed capital formation data (for residential buildings) and link them with existing data on construction of living area. For Germany, we have data available for the gross fixed capital formation according to individual types of investment (e.g. installations, equipment, and construction) in current prices [Destatis 2009]. For 2000, the investments for residential building amounted to about 141 000 Mio. Euro. The calculated construction in the year 2000 was 41.8 Mio. m^2 living area but depends very much on our assumption on the construction:demolition ratio. For an construction:demolition ratio of 5 (this is what we assumed), the cost of construction would amount to about 3 370 Euro/m^2. It has to kept in mind that there are also some major renovations included in the gross fixed capital formation, i.e. the figures include not only construction but other activities and construction cost should then be lower than the calculated values.

Gross fixed capital formation data is also available from Eurostat for all EU-27 countries for six asset types including construction work for housing [Eurostat 2009a]. The data is almost complete for the years 1995 to 2005. A first check revealed that the data for construction of housing (in the case of Germany) was consistent with the national statistics [Destatis 2009].

For modelling purposes, the assumptions for construction cost are not important, because the construction activity does not differ between the individual scenarios. However, it is important for the link of the building stock model to the IO tables to know the exact gross fixed capital formation in construction for housing (see Section 7.2.1). To conclude, we estimated the construction costs in Germany to be 3 370 Euro/m^2 living area including labour and taxes. For Spain the cost was calculated to be 2 951 Euro/m^2 living area and for Poland 725 Euro/m^2 living area.

6.2 Energy mix and energy cost data

The energy demand for heating energy is derived from the building stock model. The energy mix for space heating of households was taken from the IMPRO-Building project [Nemry et al. 2008] and is shown in Table 21.

Table 21 Energy mix for space heating in Germany, Poland, and Spain in %

Country	Coal	Oil	Gas	Electricity	Heat	Renewables	Total
Germany	1.1	27.8	44.5	3.0	15.6	7.9	100.0
Poland	23.9	6.6	13.6	0.3	41.6	14.2	100.0
Spain	1.2	35.5	22.2	23.4	0.0	17.8	100.0

The energy prices and taxes for the year 2000 were derived from various sources (mainly [IEA 2007]). In Table 22, an overview over the used cost data for the three countries under investigation is given.

Table 22 Energy prices for households in Germany, Poland, and Spain according to energy carrier in Euro/GJ

Country	Price component	Coal a)	Oil b)	Gas b)	Electricity b)	Heat c)	Renewables d)	Total e)
Germany	Total	11.41	19.31	9.36	37.32	13.39	5.71	13.33
	VAT	0.02	3.08	1.50	5.96	2.14	0.91	2.11
	Other tax	0.33	5.57	0.49	0.00	0.00	0.00	1.77
	Price w/o taxes	11.06	10.66	7.38	31.36	11.26	4.79	9.45
Poland	Total	4.02	14.55	6.41	19.72	9.78	2.01	7.18
	VAT	0.72	2.62	1.16	3.56	1.76	0.36	1.30
	Other tax	0.00	1.00	0.00	0.00	0.00	0.00	0.07
	Price w/o taxes	3.29	10.93	5.26	16.16	8.02	1.65	5.82
Spain	Total	19.43	15.91	12.74	35.32	19.43	9.72	18.68
	VAT	2.68	2.19	1.76	4.87	2.68	1.34	2.58
	Other tax	0.00	3.35	0.00	1.47	0.00	0.00	1.53
	Price w/o taxes	16.75	10.36	10.98	28.97	16.75	8.38	14.57

a) Data for Germany from [BMWi 2009], data for Poland from [IEA 2007], data for Spain interpolated based on Germany (comparison between solid fuels and gas); b) Data from [IEA 2007]; c) Data from [BMWi 2009] for Germany, data for Poland and Spain interpolated based on gas; d) Own assumption: 50 % compared to the price for solid fuels; e) weighted average taking into account the energy mix

6.3 Emission factors for household energy use

Emission factors for the use of energy in households were used to calculate the GHG emissions due to space heating. Emissions due to electricity, heat, and renewables have not been accounted for because they are covered in the IO part of the analysis (the emissions are not generated in the households directly but by industry). The household emissions thus only include emissions from coal, oil, and gas. In order to calculate the GHG emissions from household energy use, default emission factors from the

IPCC emission factor database were used.[19] The global warming potential of the individual emissions were taken from [IPCC 2001]. The resulting emission factors are 94.00, 78.81, and 56.24 kg CO_2-equivalents per GJ, respectively.

Due to different energy mixes in the individual countries, the aggregated/average household emission factors differ slightly. Only the respective shares of the three energy carriers coal, oil, and gas were taken into account (see Table 21). The resulting emission factors are: 47.71 kg CO_2-equivalents per GJ for Germany, 41.21 kg CO_2-equivalents per GJ for Spain and 35.18 kg CO_2-equivalents per GJ in the case of Poland.

[19] This database is available at: http://www.ipcc-nggip.iges.or.jp/EFDB/main.php.

7 Input-Output model

The input-output model was used to calculate the socio-economic (or macroeconomic) impact of the policy scenarios on the following parameters:

- Value added;
- Employment;
- Compensation of employees;
- Greenhouse gas emissions from the total economy (w/o household emissions);
- Tax revenue;
- Effects on the household, government, and investment (gross fixed capital formation) budgets;
- Welfare effect.[20]

The methodology used for the modelling is described in detail in Section 7.1. In Section 7.2, the linking of the building stock model and the input-output model is presented.

7.1 Methodology

The calculation of the socio-economic impacts of the policy scenarios was accomplished using an input-output model. The model is based on an input-output matrix of technical coefficients, $A = (a_{ij})$ with $i, j = 1, \dots, n$ (where n is the number of commodities), which represents the direct requirements of commodity i needed to produce a physical unit of commodity j [Leontief 1986, ten Raa & Rueda-Cantuche 2003] The matrix of technical coefficients A is commonly used for the analysis by means of the so-called quantity equation or material balance: $x = Ax + y$ with the vector Ax reflecting the requirements for intermediate inputs and vector y representing the exogenous aggregate final demand. With this relationship, e.g. the output requirements to satisfy a certain final demand level can be determined. The model captures both direct effects on the output levels which depends on variation in final demand y and additional indirect effects determined by the structure of the A-matrix [ten Raa & Rueda-Cantuche 2003]

Input-output analysis can be used and has frequently been used to analyse the impact of changes in final demand on total output. In addition, input-output systems can be applied to evaluate the impacts of policies on other economic variables such as labour, capital, energy and emissions, by using the appropriate extensions [Eurostat 2008]. The quantity equation can be transformed to $x = (I - A)^{-1}y$ and subsequently, an extension offers multiple approaches for analysis: $z = B(I - A)^{-1}y$. The matrix B includes the input coefficients of the selected variables for the analysis (e.g. intermediates, labour, capital, energy, emissions) and vector z shows the direct and indirect requirements (e.g. energy, labour, capital) or joint products (emissions) for the produced goods and services [Eurostat 2008]. Within this

[20] The welfare effect was measured by the net effects of the policy on available budget. First, the differences between the energy cost savings and additional expenditure for renovation and refurbishment are calculated. If the energy cost savings exceed the additional expenditure, a positive welfare effect is assumed (expenditure of the economy is increased). In addition, indirect effects due to the recycling of tax revenue and the compensation of employees are taken into account. These indirect effects can lead to an increase (positive welfare effect) or a decrease (negative welfare effect) in the final demand of households.

framework, the input-output model can be used to assess the impact of e.g. environmental policies on productivity, energy issues, and other parameters.

For assessing the policy scenarios considered in this study, the output from the building stock model are used as input parameters for the macroeconomic assessment, e.g. the demand for energy and the demand for construction, renovation and refurbishment activities. The changes in household consumption and gross fixed capital formation as well as the government budget (see Section 7.3) allow us to determine the output multipliers, employment, and value-added effects as well as the impacts on other parameters by using the input-output equation system.

To perform the analysis, the symmetric input-output tables (SIOT) of the year 2000 for Germany, Poland, and Spain compiled by the IPTS during the estimation of an aggregated EU-27 SIOT were used [Rueda-Cantuche et al. 2009]. The SIOTs consists of 59 industries and 59 commodities at a NACE-2 digits level. The SIOTs already included data on the compensation of employees and tax revenues (taxes less subsidies on products and other net taxes on production). To calculate the employment impacts, EU KLEMS data on employment were used to compile the respective *B* matrix [EU KLEMS 2008]. Emission data for the greenhouse gas emissions of CO_2, CH_4, and N_2O was retrieved from environmental satellite accounts from Eurostat which were completed by the DEIA project run by IPTS in 2007 [Heijungs et al. 2007].

The conversion of the results from the building stock model to household demand, gross fixed capital formation, and government budget, i.e. the mapping of the changes into the NACE categories of final demand, is described more in detail in the following sections.

In a first step of the modelling, the total final demand (the sum of household and government expenditure as well as GFCF investment) was assumed to be constant. In a second step, the changes of tax revenue and the compensation of employees is incorporated into the model. It was assumed that tax revenues obtained from each of the policy options are re-distributed again to households in order to keep the government budget unchanged. Otherwise, that would result in undesirable distorted welfare effects (for some financing options, however, the government budget was changed). Also changes of the compensation of employees is allocated to the household budget. This was done by assuming a 100 % spending of additional income which can be seen as a maximum case. Sensitivity analyses have shown that the incorporation of this feedback loop (tax revenue and compensation of employees) has only very little effects on the results. The maximum difference for all socio-economic parameters between no-loop and loop option did not exceed 0.1 %.

7.2 Transfer of the building stock model results to the input-output model

7.2.1 Construction, renovation and refurbishment costs

The building stock model was used to calculate the costs for major renovation, window and roof refurbishment as well as the construction of new buildings (see Section 6). To transfer the cost data to the IO tables, we have to distribute the costs to different sectors of the economy (NACE categories) in the IO table. To this end, prices without tax (VAT) are used. It was assumed that renovation, refurbishment and construction activities are captured in the final demand column of gross fixed capital formation (GFCF).

To calculate the change in GFCF, the difference between the sum of all the costs for construction, major renovation, and the refurbishment activities for the individual scenarios and the reference scenario is calculated. There exist, however, inconsistencies between the calculated costs for construction, renovation and refurbishment and the data in the input-output framework. The calculated costs should thus be adjusted. Gross fixed capital formation is available from [Eurostat 2009a] and amounts e.g. to 140 920 Mio. Euro for Germany (see Section 6.1.4). The investment according to our model (the sum of all construction, refurbishment, and renovation activities) was calculated (e.g. 167 060 Mio. Euro in Germany). As some refurbishment activities (e.g. ceilings, cellars) are not included in our model, we overestimate the investment in buildings. We thus include a correction factor which transfers our estimated change into a “real” change in GFCF. This factor (about 0.83 in Germany) thus translates a calculated change in construction activity of 1 Euro (by our model) to a change of 0.83 Euro in the input-output model.

The gross fixed capital formation for residential buildings (construction, renovation, and refurbishment) not only goes to the construction sector but also to other NACE sectors. According to data from Austria, about 74 % of gross fixed capital formation takes place in the construction sector, followed by the sectors ‘other business services’ and ‘other non-metallic mineral products’ (Table 23). These shares derived from Austria were used to distribute the impacts to the GFCF sectors. For example, assume the calculated total change in construction investment to be 2 380 Mio. Euro for Germany in a specific scenario. Applying the correction factor, this corresponds to a change of about 1 980 Mio. Euro in the input-output model. This value is then distributed according to the respective shares to the eleven construction-related NACE sectors.

Table 23 Relative share of gross fixed capital formation for dwellings according to industry sectors

Sector	**Gross fixed capital formation for dwellings**	
	1000 Euro	Relative share
Products of agriculture, hunting	5 664	0.1%
Other mining and quarrying products	91 749	0.9%
Wood and products of wood	774 768	7.8%
Chemicals, chemical products	32 952	0.3%
Rubber and plastic products	104 644	1.0%
Other non-metallic mineral products	498 747	5.0%
Fabricated metal products	155 407	1.6%
Machinery and equipment n.e.c.	17 418	0.2%
Construction work	7 342 971	73.6%
Real estate services	134 838	1.4%
Other business services	817 832	8.2%
Total	**9 976 990**	**100.0%**

7.2.2 Energy costs

Concerning the energy demand, the change in demand for heating energy was derived from the building stock model. The energy mix was derived from the IMPRO-Building report [Nemry et al. 2008]. Energy prices were derived from various sources (see Section 6.2). From this, the cost for energy (without VAT and other taxes) and the change in energy cost of a policy scenario compared to the reference scenario is derived. This change has than to be applied to the respective energy-related NACE sectors (Table 24). The share of the individual energy-related NACE sectors was calculated by using data from [Destatis 2008] on the energy use of private households for space heating and other purposes (e.g. lightning, appliances, private transportation) in Germany and taking into account expenditure data from the input-output tables for Germany [Rueda-Cantuche et al. 2009]. For countries without information on energy use by households according to energy carrier and purpose, the existing shares of final demand in the energy-related sectors from the input-output tables were used (Table 24).

Table 24 Energy-related industry sectors and corresponding energy carriers

Sector	Energy carrier	Share Germany	Share Spain	Share Poland
Products of forestry, logging and related services	Biomass	1.8%	0.5%	7.2%
Coal and lignite; peat	Coal	2.0%	0.1%	2.9%
Coke, refined petroleum products and nuclear fuels	Oil	20.4%	49.7%	30.4%
Electrical energy, gas, steam and hot water	Electricity, gas, and heat	75.9%	49.7%	59.5%

7.3 Financing options

To calculate the macroeconomic effects of the policy scenarios, new final demand vectors for the three categories households (HH), investment (GFCF) and government (GOV) were calculated (see Section 7.1). To improve the analysis of different policy measures, five different financing options were included into the model (Table 25).

For all options, it was assumed that the total final demand (the sum of spending of households, government and investment) remains constant. The financing options allow for a shift of expenditure between individual items within one final demand category (e.g. households spend less on energy and more on other items) and between the categories of final demand (increase of expenditure for investments and less expenditure of households). A shift of spending between single years was not included into the analysis. However, side effects of these shifts can not be captured with the input-output model, e.g. the effect of reduced investment on the production base and thus the productivity in later years.

It has to be mentioned that the financing options can be seen as extreme cases (e.g. 100 % financing by government). The financing options should thus be seen more as examples that serve to illustrate the possible bandwidth of the socio-economic impacts. In Figure 11, a scheme of the options is shown.

Table 25 Financing options included into the IO model

Financing option	Description	Comment
Option 1	Both GFCF and HH budget were kept constant. This leads (in general) to a decrease in the energy sectors for HH and an increase in all other sectors. In the GFCF budget, construction increases (and the other sector assumed to receive construction investments, see above) and other sectors decrease.	This assumes that households would save money because demand for energy is reduced and buy more other goods instead. The money available for investment would shift from non-construction investment categories (e.g. machinery, equipment) to construction-related sectors.
Option 2	In HH budget, energy sectors decrease. In GFCF budget, construction sectors increase. The needed money is taken away from HH budget (all non-energy sectors). Total HH budget decreases, total GFCF budget increases.	This assumes that households would invest more money into renovation and refurbishment and would reduce consumption of other goods. The consumption of energy commodities remains unchanged (i.e. only the savings from the refurbishment measures are taken into account).
Option 3	In HH budget, energy sectors decrease. In GFCF budget, construction sectors increase (the non-construction sectors will decrease by the same amount, first). Then, the saved money in the HH budget is used to further increase GFCF budget (all non-construction sectors). Total HH budget decreases, total GFCF budget increases.	This option would be the case if households save money from energy efficiency investment (energy savings) and if they would give this money to banks. These would loan it or invest the money (increase in gross fixed capital formation).
Option 4	In HH budget, energy sectors decrease. In GFCF budget, construction sectors increase. The net change is applied to the GOV sector. In general, there is an decrease in GOV budget (additional construction	This option would be a government financing refurbishment and renovation actions but at the same time taking also away the benefits from energy savings from private households.

Financing option	Description	Comment
	sector investment is greater than energy savings by households). The change is applied to all GOV sectors proportionally to their initial budget share.	
Option 5	In HH budget, energy sectors decrease. In GFCF budget, construction sectors increase. Households will spend their money on other goods (household budget is kept fixed). The net change in GFCF sector is applied to the GOV sector. The GOV budget will decrease (additional construction takes place). The change is applied to all GOV sectors proportionally to their initial budget share.	This option would be a government financing refurbishment and renovation actions but – compared to option 4 - leave the benefits from energy savings with the private households.
Option 6 (not included)	In HH budget, energy sectors decrease. In GFCF budget, construction sectors increase. Investment will be reduced in other GFCF sectors (GFCF budget is kept fixed). The net change in HH sector is applied to the GOV sector. The GOV budget will increase (energy saving occurs, in general). The change is applied to all GOV sectors proportionally to their initial budget share.	This option would be a government that would not finance refurbishment and renovation actions but at the same time take away the benefits due to energy savings from private households

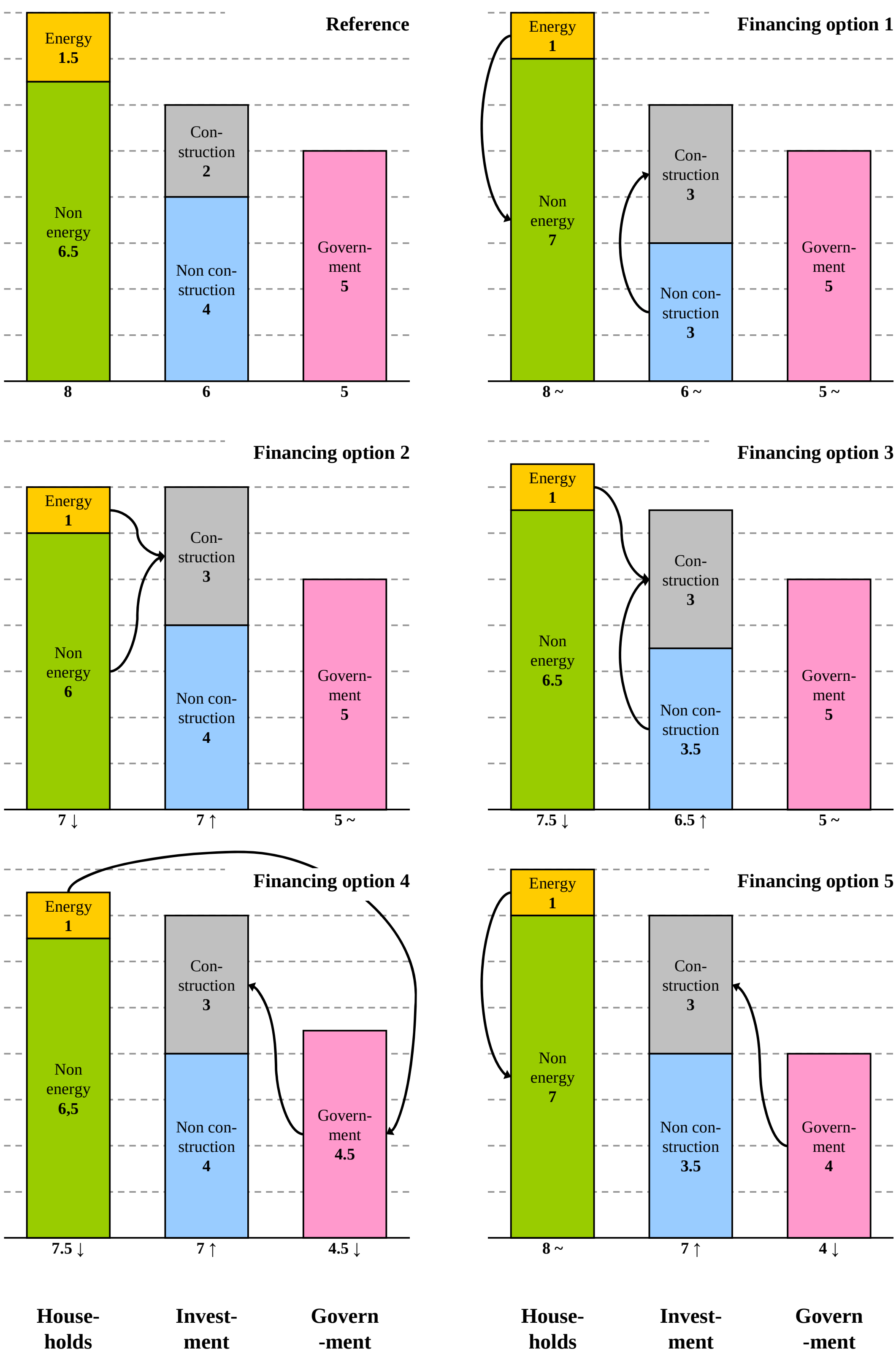

Figure 11 **Schematic illustration of the different financing options analysed**
Note that in this case the additional investment is greater than the energy cost saved

7.4 Multipliers

The input-output model can be used to calculate the output multiplier effects, as well as the multipliers for the socioeconomic parameters under investigation. Figure 12 shows the value added multipliers for several final demand structures. As an example, the average final demand from households in Spain shows a VA multiplier of about 0.6. Thus, for every Euro spent by Spanish households, value added of 0.6 Euro is generated.

The two categories HH non-energy and HH energy show the multipliers for the energy-related sectors (the sectors household pay energy costs to) and all other sectors (non-energy) households buy consumption goods from. On average, the VA multipliers for energy items is by far lower than for the other consumption categories in all countries. Thus, if households save energy costs and they spend the saved money on other consumption items, value added of the economy will increase (this is the case for e.g. financing option 1).

The gross fixed capital formation budget shows lower VA multipliers compared to the final demand by households. For construction-activity related investments, VA multipliers are higher in Germany and Spain but lower in Poland. A shift from investments to construction (as it is the case when expenditures for renovation and refurbishment activities increase) will thus lead to an overall increase in value added in Germany and Spain while in Poland, value added will decrease.

The highest value added multipliers can be found for the government budget for all countries. Consequently, changes in government budget – as it is the case in financing options 4 and 5 (see Section 7.3) – will lead to high valued added impacts.

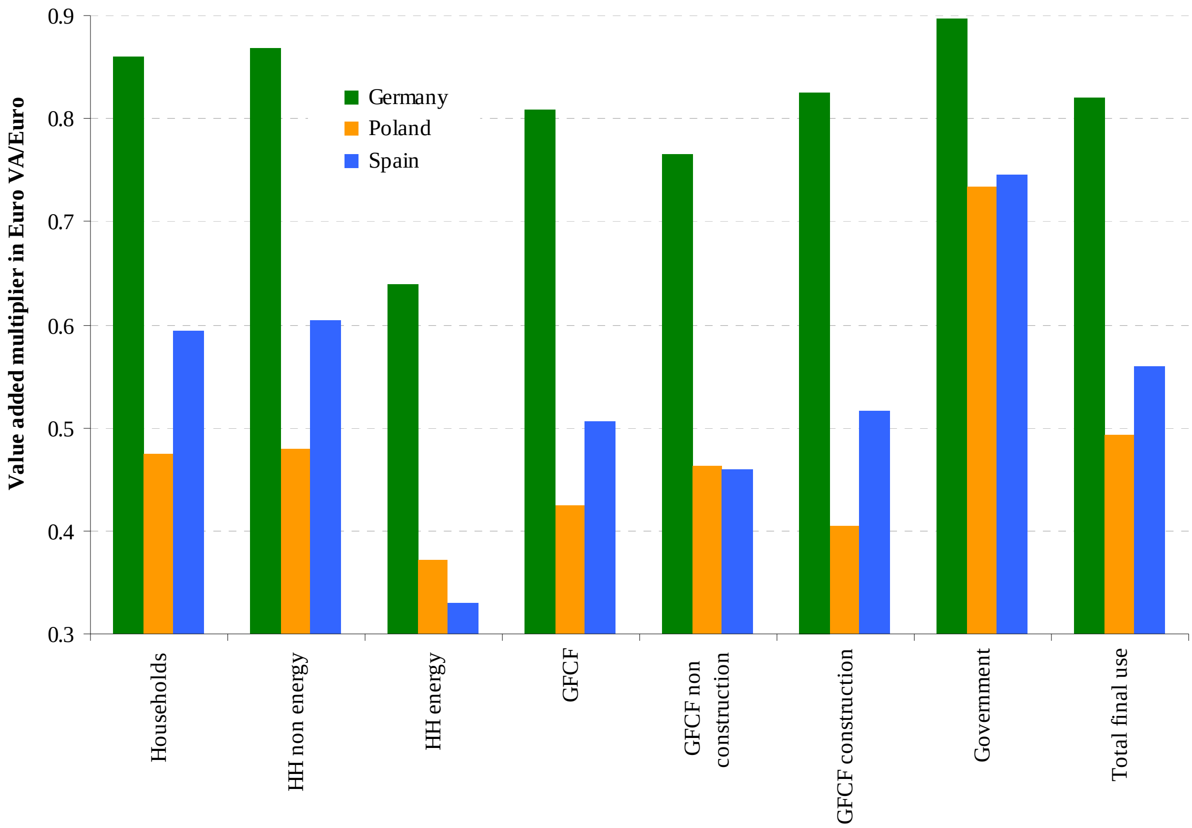

Figure 12 Value added multipliers according to different final demand categories

In Figure 13, the employment multipliers are displayed for the same final demand categories. For households, the picture is similar than for the VA multipliers. For all countries, the employment multipliers for energy-related spending are lower than for the average household budget. Energy savings will thus lead to higher employment when households spend the saved money on other consumption items (financing option 1).

For Germany and Spain, the employment multipliers with regard to gross fixed capital formation are higher in the construction-related sectors, while for Poland, the multiplier is lower. Like for VA, a shift of investments to construction by the expense of investments in other items (financing option 1) will lead to higher employment in Germany and Spain and to a loss of employment in Poland.

Total government budget multipliers are high compared to final demand by households and GFCF in Germany and especially in Poland. Interestingly, in Spain, the employment multiplier for households is higher than for government. Nevertheless, a change in government expenditure will lead to high employment impacts, especially when government spending is reallocated to construction sectors.

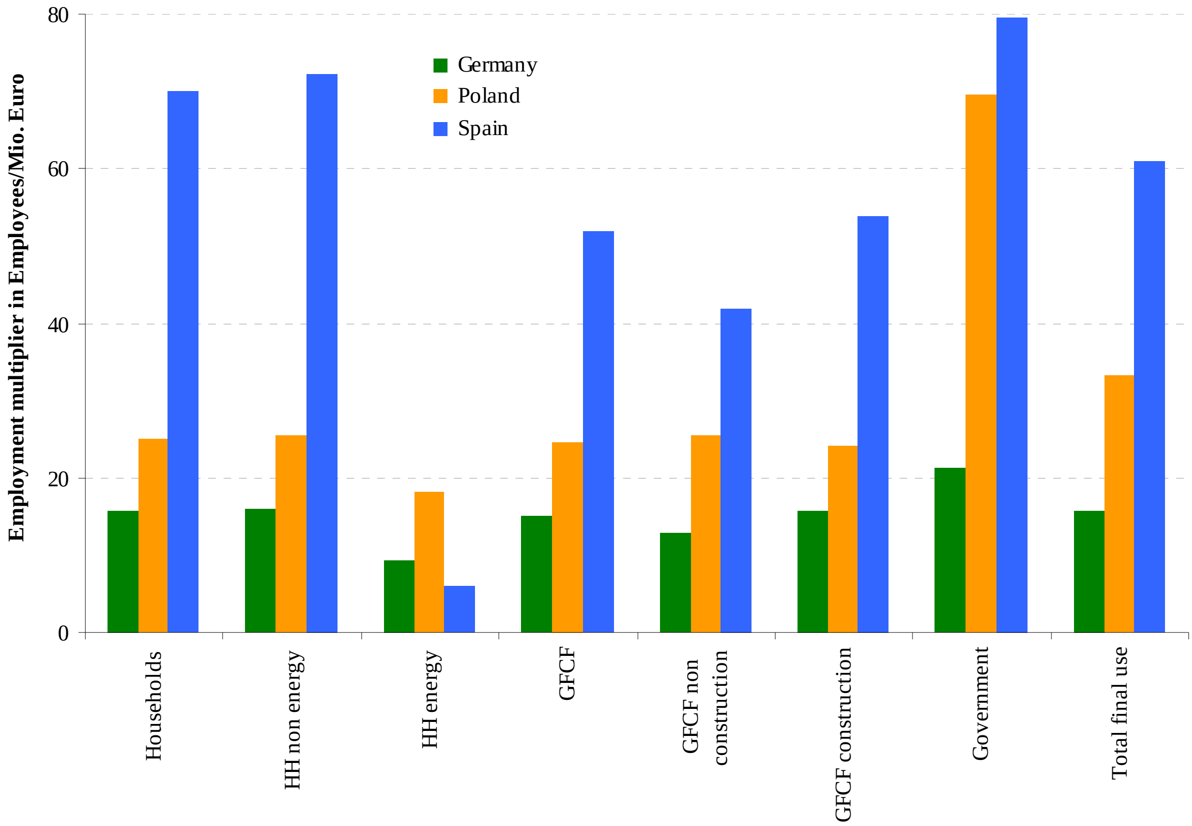

Figure 13 Employment multipliers according to different final demand categories

8 Scenario description

In total, ten different policy scenarios have been included into the analysis. In Table 26, a summary of the scenarios is given. Each scenario will be described in detail in the following sections.

Table 26 Overview over the scenarios included into the analysis

Short name/ Acronym	Scenario name	Scenario description
Reference	Reference scenario	Up to 2008 the scenario reflects the historical development of the energy efficiency levels at the installation of building elements. The 2008 distribution is fixed for all subsequent years (perpetuation).
EE Boundary High	Energy efficiency boundary high scenario	Theoretical ‘what-if’ scenario. Always the highest EE level in place. Allows calculating the theoretical maximum energy saving compared to reference.
Full Coop	Full cost optimal scenario	From 2009 on, all new buildings, major renovation and retrofits are carried out according to the cost optimal energy efficiency level (EE level 3). Major renovation and retrofitting cycles are the same as in the reference scenario.
Full Coop Acc	Full cost optimal accelerated scenario	From 2009 on, all new buildings, major renovation and retrofits are carried out according to the cost optimal energy efficiency level. Retrofitting cycles of building elements are accelerated compared to the reference scenario.
EPBD Recast	EPBD recast scenario	Follows the existing policies plus those stated in the recast of the EPBD. From 2006 to 2011, performance requirements according to the existing EPBD are implemented in new buildings and major renovations of buildings above 1 000 m^2. From 2012 on, the performance requirements are applied to all new buildings and to major renovations of all buildings without minimum size limit. From 2017 on, the cost optimal minimum performance requirements for all new construction and major renovation is assumed.
Coop RR&WR	Cost optimal retrofitting of roofs and windows	Energy losses through roofs and windows are reduced to levels considered as cost optimal following the normal renovation and retrofitting cycles. Full cost optimal retrofitting starts in 2017 when also all major renovations have to reach the cost optimal EE level according to the EPBD recast proposal. From 2014 on cost optimal building elements are installed in a certain increasing proportion.
Coop RR Acc	Accelerated cost optimal retrofitting of roofs	The objective of the policy is to achieve that the energy losses through roofs and windows are reduced to levels considered as cost optimal in an accelerated way. In the period 2014-2023, the roof refurbishment is accelerated. All existing non cost optimal roofs older than 10 years will be refurbished unless the building undergoes major renovation or is demolished.
Coop WR Acc	Accelerated cost optimal retrofitting of windows	The objective of the policy is to achieve that the energy losses through roofs and windows are reduced to levels considered as cost optimal in an accelerated way. In the period 2014-2023, the window refurbishment is accelerated. All existing non cost optimal windows older than 10 years will be refurbished unless the building undergoes major renovation or is demolished.
Coop RR&WR Acc	Accelerated cost optimal retrofitting of roofs and windows	The objective of the policy is to achieve that the energy losses through roofs and windows are reduced to levels considered as cost optimal in an accelerated way. In the period 2014-2023, roof and window refurbishment is accelerated. All existing non cost optimal roofs and windows older than 10 years will be refurbished unless the building undergoes major renovation or is demolished.
EE Boundary Low	Energy efficiency boundary low scenario	Always the lowest EE level in place. Allows calculating the theoretical minimum energy performance compared to reference. Other indicators not meaningful.

8.1 Reference scenario

The reference scenario is described in detail in Table 27. For the years up to 2005, for some scenarios up to 2008, this scenario is the reference scenario. For the years from 2006, the EPBD recast scenario (see Section 8.5) could be considered as the reference scenario.

The reference scenario assumes no further efficiency improvement from 2008 on. Energy efficiency levels are kept constant in future (see Figure 8). The renovation cycles were assumed to be 40 years for major renovation and 20 years for window and roof refurbishment (see Section 5.2).

Table 27 Description of the reference scenario

Short name/Acronym	Reference
Scenario name	Reference scenario
Scenario definition	The scenario reflects the historical development of the energy efficiency levels at the installation of building elements until 2008. The 2008 distribution over energy efficiency levels at new construction, major renovation and retrofitting of individual building elements, which reflects current practice, is fixed for all subsequent years (perpetuation). There are constant major renovation and retrofitting cycles of a typical duration.
Policy measures	Not relevant. The degrees of implementation of existing policies are assumed to remain at 2008 levels.
Modelling implementation	The energy efficiency level of building elements installed and new construction are assumed as follows: • Up to 1973: only EE level 0; • From 1974 to 1979: EE level 0 and EE level 1; • From 1980 to 1990: only EE level 1; • 1990-2005: EE levels 1 and 2 (with a substantial level of 1 still remaining in year 2005). Energy efficiency levels are the same for construction, major renovation or refurbishment of single building elements. From 2009 on, the same EE level shares as in the year 2008 were assumed. The major renovation cycle is 40 years. Roof and window retrofitting cycles were assumed to be 20 years. No special attention was paid to ventilation losses.

8.2 Energy efficiency boundary high scenario

The energy efficiency boundary high scenario is a theoretical “what-if” scenario. It assumes that refurbishment and renovation measures are always performed according to the highest energy efficiency level (Table 28).

Table 28 Description of the energy efficiency boundary high scenario

Short name/Acronym	EE Boundary High
Scenario name	Energy efficiency boundary high scenario
Scenario definition	Always the highest EE level in place. Allows calculating the theoretical maximum energy saving compared to reference. Other indicators not meaningful.
Policy measures	Not relevant. Theoretical ‘what-if’ scenario.
Modelling implementation	From 1900 to 2100 always only EE level 3 for all refurbishment and renovation activities. The same major renovation and refurbishment cycles than in the reference scenario (40 years and 20 years).

8.3 Full cost optimal scenario

The full cost optimal scenario is a theoretical ‘what-if’ scenario. It assumes that construction, refurbishment and renovation measures from 2009 are always performed according to the highest energy efficiency level (Table 29). Up to 2008, the energy efficiency levels are assumed as in the reference scenario.

Table 29 Description of the full cost optimal scenario

Short name/Acronym	Full Coop
Scenario name	Full cost optimal scenario
Scenario definition	From 2009 on, all construction, renovation and refurbishment activities are carried out according to the cost optimal energy efficiency level. Major renovation and retrofitting cycles are the same as in the reference scenario.
Policy measures	Not relevant. Theoretical ‘what-if’ scenario.
Modelling implementation	Up to 2008, EE levels installed as in reference scenario. From 2009 on, all building elements get installed only at the highest EE level. The same major renovation and refurbishment cycles than in the reference scenario (40 years and 20 years).

8.4 Full cost optimal accelerated scenario

The full cost optimal accelerated scenario is also theoretical ‘what-if’ scenario. It assumes that construction, refurbishment and renovation measures from 2009 are always performed according to the highest energy efficiency level as in the full cost optimal scenario (Table 30). Up to 2008, the energy efficiency levels are assumed as in the reference scenario. In addition, the refurbishment cycles of windows and roofs are accelerated from 2009 to 2018. In this period, the building element refurbishment cycles is shortened by 50 % (windows and roofs older than 10 years are refurbished). The acceleration is only applied to building elements with a energy efficiency level of 0, 1, or 2. For building elements already showing the highest energy efficiency level, acceleration of the refurbishment cycle is not necessary.

Table 30 Description of the full cost optimal accelerated scenario

Short name/Acronym	Full Coop Acc
Scenario name	Full cost optimal accelerated scenario
Scenario definition	From 2009 on, all new buildings, major renovation and retrofits are carried out according to the cost optimal energy efficiency level. Retrofitting cycles of building elements are accelerated compared to the reference scenario.
Policy measures	Not relevant. Theoretical ‘what-if’ scenario.
Modelling implementation	Up to 2008, EE levels installed as in reference scenario. From 2009 on, all building elements get installed only at the highest EE level. The same major renovation is assumed than in the reference scenario (40 years). The retrofitting cycles of windows and roofs are shortened by 50 % from 2009 to 2018 compared to the reference scenario (10 years). Retrofitting cycles of building elements already showing the highest EE level are kept the same than in the reference scenario.

8.5 EPBD recast scenario

The EPBD recast scenario follows the existing policies included into the Commission proposal on the recast of the EPBD [COM(2008) 780 final]. From 2006 to 2011, for all new buildings, the major renovation of high-rise buildings, and a share of multi-family buildings (1 000 m^2 threshold), EE level 2 applies. For the rest of the multi-family buildings and single-family houses, the same EE level than in the reference scenario was assumed. From 2012 on, all new construction and major renovation activities are performed according to EE level 2 (no threshold on size). From 2014 on, energy efficiency level 3 phases in. An increasing share of energy efficiency level 3 is assumed until 2016. From 2017, on energy efficiency level 3 is applied to all construction, major renovation and refurbishment activities.

Table 31 Description of the EPBD recast scenario

Short name/Acronym	EPBD recast
Scenario name	EPBD recast scenario
Scenario definition	Up to 2005 the scenario is identical to the reference scenario. From 2006 to 2011, national minimum performance requirements according to the existing EPBD are assumed for new buildings and major renovations of buildings above 1 000m^2. From 2012 on, the minimum performance requirements are applied to all new buildings and to major renovations of all buildings without a minimum size limit. From 2013 to 2016 it is assumed that all subsidised construction and major renovation is carried out so as to attain the cost optimal energy efficiency levels, all other new construction and major renovation is done according to the 'old' minimum performance requirements. From 2017 on all new construction and major renovation follows cost optimal minimum performance requirements.
Policy measures	Existing policies plus those included in the Commission proposal on the recast of the EPBD
Modelling implementation	The energy efficiency levels of building elements installed are assumed as follows: • Up to 2005 identical to reference scenario; • From 2006-2011: all new buildings and MR of high-rise buildings: at least level 2; the same for a certain percentage of major renovations of multi-family buildings. All major renovations of single family houses and of the rest of the multi-family buildings: same as in reference scenario. Retrofits outside major renovations: at least level of reference scenario but never worse than the 'old' building element that undergoes retrofitting ; • From 2012-2013: all new construction and major renovations: al least level 2. Retrofits outside major renovations: at least level of reference scenario but never worse than the 'old' building element that undergoes retrofitting; • From 2014-2016: all new construction and major renovations: al least level 2 or level 3 (with increasing share of 3, to be coordinated with policies on financing – all subsidised activities have to lead to level 3). Retrofits outside major renovations: al least level of reference scenario but never worse than the 'old' building element that undergoes retrofitting • From 2017 on: all new construction and major renovations: level 3. Retrofits outside major renovations: at least level of reference scenario but never worse than the 'old' building element that undergoes retrofitting The major renovation and retrofitting cycles are assumed as in reference scenario.

8.6 Cost optimal retrofitting of roofs and windows scenario

The cost optimal retrofitting of roofs and windows scenario aims at reduce the energy losses through roofs and windows (Table 32). A full cost optimal retrofitting is assumed from 2017 on (when also major renovations have to reach the cost optimal EE level according to the EPBD recast proposal).

Table 32 Description of the cost optimal retrofitting of roofs and windows scenario

Short name/Acronym	Coop RR&WR
Scenario name	Cost optimal retrofitting of roofs and windows
Scenario definition	The objective of the policy is to achieve that the energy losses through roofs and windows are reduced to levels considered as cost optimal following the normal renovation and retrofitting cycles. Full cost optimal retrofitting starts in 2017 when also all major renovations have to reach the cost optimal EE level according to the Proposal of the EPBD Recast. From 2014 on cost optimal building elements are installed in a certain increasing proportion. (The EPBD Recast proposal includes that from 2014 on no incentives may be given if minimum energy performance requirements are not cost optimal.)
Policy measures	A combination of minimum performance requirements for windows, demanding U values to be at cost optimal level (in reality the mean U of the windows installed would then be lower than the limit value at the time of installation and then slowly rise during its life time because of wear), and minimum performance requirements for roofs (e.g. minimum thickness of insulation, depending on roof type, material type and installation mode; installation quality standards).
Modelling implementation	Energy efficiency (EE) levels of roof and windows installed are the same as in the EPBD Recast scenario until 2013. From 2014 to 2016, the EE levels are partly cost optimal (i.e. increasing share of EE level 3). From 2017 on, only EE level 3 is installed. EE levels for major refurbishment are assumed the same as in the EPBD Recast scenario. The roofs and windows retrofitting cycles are the same as in the reference scenario.

8.7 Accelerated cost optimal retrofitting of roofs scenario

The accelerated cost optimal retrofitting of roofs scenario is a scenario based on the EPBD recast scenario with an accelerated retrofitting of roofs between 2014 and 2023 (Table 33). In addition, it is assumed that from 2014 on, all roofs are installed according to the cost optimal EE level.

Table 33 Description of the accelerated cost optimal retrofitting of roofs scenario

Short name/Acronym	Coop Acc RR
Scenario name	Accelerated cost optimal retrofitting of roofs
Scenario definition	There are policies to achieve that the energy losses through roofs are reduced to levels considered as cost optimal in an accelerated way. Within ten years all roofs shall be retrofitted accordingly. The accelerated roof retrofitting starts in 2014. By 2023 all roofs have to achieve the cost optimal energy efficiency level (the EPBD recast proposal includes that from 2014 on no incentives may be given if minimum energy performance requirements are not cost optimal). In the period 2014-2023, the roof refurbishment is accelerated. All existing non cost optimal roofs older than 10 years will be refurbished unless the building undergoes major renovation or is demolished.
Policy measures	For example a combination of minimum performance requirements for roofs (e.g. minimum thickness of insulation material, depending on roof type, material type and installation mode; installation quality standards) and financial incentives and/or obligations to retrofit roofs within the accelerated retrofitting period.
Modelling implementation	EE levels of roofs installed are assumed the same as in the EPBD recast scenario until 2013. From 2014 on, the EE level is assumed to be cost optimal (i.e. EE level 3). The roof retrofitting cycle is the same as in the EPBD recast scenario until 2013. From 2014 to 2023, the roof refurbishment is accelerated. All existing non cost optimal roofs older than 10 years will be refurbished unless the building undergoes major renovation or is demolished. From 2024 on, normal duration of the roof retrofitting cycle is assumed again. The EE levels and retrofitting cycles of other building elements installed and major renovation are the same as in the EPBD recast scenario.

8.8 Accelerated cost optimal retrofitting of windows scenario

The accelerated cost optimal retrofitting of windows scenario is comparable to the accelerated cost optimal retrofitting of roofs scenario (see Section 8.7). The scenario is based on the EPBD recast scenario with an accelerated retrofitting of windows between 2014 and 2023 (Table 34). In addition, it is assumed that from 2014 on, all windows are installed according to the cost optimal EE level.

Table 34 Description of the accelerated cost optimal retrofitting of windows scenario

Short name/Acronym	Coop Acc WR
Scenario name	Accelerated cost optimal retrofitting of windows
Scenario definition	There are policies to achieve that the energy losses through windows are reduced to levels considered as cost optimal in an accelerated way. Within ten years all windows shall be retrofitted accordingly. The accelerated window retrofitting starts in 2014. By 2023 all windows have to achieve the cost optimal energy efficiency level (the EPBD recast proposal includes that from 2014 on no incentives may be given if minimum energy performance requirements are not cost optimal). In the period 2014-2023, the window refurbishment is accelerated. All existing non cost optimal windows older than 10 years will be refurbished unless the building undergoes major renovation or is demolished.
Policy measures	For example a combination of minimum performance requirements for windows, which demand U values to be at cost optimal level (in reality the mean U of the windows installed would then be lower than the limit value at the time of installation and then slowly rise during its life time because of wear), and financial incentives and/or obligations to retrofit windows within the accelerated retrofitting period.
Modelling implementation	EE levels of windows installed are assumed the same as in the EPBD recast scenario until 2013. From 2014 on, the EE level is assumed to be cost optimal (i.e. EE level 3). The window retrofitting cycle is the same as in the EPBD recast scenario until 2013. From 2014 to 2023, the window refurbishment is accelerated. All existing non cost optimal windows older than 10 years will be refurbished unless the building undergoes major renovation or is demolished. From 2024 on, normal duration of the window retrofitting cycle is assumed again. The EE levels and retrofitting cycles of other building elements installed and major renovation are the same as in the EPBD recast scenario.

8.9 Accelerated cost optimal retrofitting of roofs & windows scenario

The accelerated cost optimal retrofitting of roofs and windows scenario is a combination of the Coop Acc RR and Coop Acc WR scenarios. Again, this scenario is based on the EPBD recast scenario. Both, roof retrofitting and window retrofitting are accelerated between 2014 and 2023 (Table 35). Also, it is assumed that from the beginning of the acceleration in 2014, the roof and window refurbishment is performed according to the cost optimal energy efficiency level (EE level 3).

Within ten years (by 2023) all roofs and windows have to achieve the cost optimal energy efficiency level 3. From 2024 on, the normal refurbishment cycle of 20 years is applied again in this scenario.

The policy measures or instruments are the same than for the accelerated retrofitting of roofs (see Section 8.7) and the 8.8). These measures could include the implementation of minimum performance requirements for the individual building elements (which would assure that the retrofitting is accomplished following cost optimal energy efficiency levels). Financial incentives or even obligations would ensure that the building element refurbishment cycles are accelerated.

Table 35 Description of the accelerated cost optimal retrofitting of roofs and windows scenario

Short name/Acronym	Coop Acc RR&WR
Scenario name	Accelerated cost optimal retrofitting of roofs and windows
Scenario definition	There are policies to achieve that the energy losses through roofs and windows are reduced to levels considered as cost optimal in an accelerated way. Within ten years all roofs and windows shall be retrofitted accordingly. The accelerated roofs and window retrofitting starts in 2014. By 2023 all roofs and windows have to achieve the cost optimal energy efficiency level (the EPBD recast proposal includes that from 2014 on no incentives may be given if minimum energy performance requirements are not cost optimal.) In the period 2014-2023, the roofs and window refurbishment is accelerated. All existing non cost optimal roofs and windows older than 10 years will be refurbished unless the building undergoes major renovation or is demolished.
Policy measures	Policy measures could be a combination of minimum performance requirements for building elements requesting them to be at cost optimal level, and financial incentives and/or obligations to retrofit building elements within the accelerated retrofitting period.
Modelling implementation	EE levels of roofs and windows installed are assumed the same as in the EPBD recast scenario until 2013. From 2014 on, the EE level is assumed to be cost optimal (i.e. EE level 3). The roof and window retrofitting cycle is the same as in the EPBD recast scenario until 2013. From 2014 to 2023, the roof and window refurbishment is accelerated. All existing non cost optimal roofs and windows older than 10 years will be refurbished unless the building undergoes major renovation or is demolished. From 2024 on, normal duration of the roof and window retrofitting cycle is assumed again. The EE levels and retrofitting cycle of major renovation are the same as in the EPBD recast scenario.

8.10 Energy efficiency boundary low scenario

The energy efficiency boundary low scenario is a theoretical “what-if” scenario. It assumes that refurbishment and renovation measures are always performed according to the lowest energy efficiency level (Table 36).

Table 36 Description of the energy efficiency boundary low scenario

Short name/Acronym	EE Boundary Low
Scenario name	Energy efficiency boundary low scenario
Scenario definition	Always the lowest EE level in place. Allows calculating the theoretical minimum energy performance compared to reference. Other indicators not meaningful.
Policy measures	Not relevant. Theoretical ‘what-if’ scenario.
Modelling implementation	From 1900 to 2100 always only EE level 0 for all refurbishment and renovation activities. The same major renovation and refurbishment cycles than in the reference scenario (40 years and 20 years).

9 Policy scenario analysis

In this chapter, we will summarise the results of the policy scenario analysis. First, we will present the results of the building stock model (Section 9.1) which includes the building stock composition according to energy efficiency levels, the renovation and refurbishment activity and the energy demand according to the different scenarios. Finally, we will display the GHG emission reduction potential and the net cost of the different policy scenarios. In Section 9.2, the results from the input-output model, i.e. the socio-economic impacts of the policy scenarios are shown. The individual policy scenarios are then assessed more in detail (Section 9.3). Finally, Section 9.4 contains the results of the sensitivity analyses performed in this study.

9.1 Results from the building stock model

9.1.1 Building stock composition according to energy efficiency level

The building stock model allows us to calculate the composition of the building stock according to the EE level for the scenarios.[21] We assumed four different EE levels for the major renovation status (Section 5.2.1). The relative share of EE level 0 in the building stock is shown in Figure 14. As assumed, in the EE Boundary Low scenario 100 % of the building stock belongs to EE level 0 while for the EE Boundary High scenario, 100 % of the building stock was attributed to EE level 3. For all other scenarios, the share of EE level 0 is identical: the share decreases from about 1/3 in 2000 to 0 % in 2020.

The relative share in EE level 1 is depicted in Figure 15. Besides the EE Boundary High and Low scenarios, all scenarios show a share of about 60 % in the year 2000. The share of EE level 1 peaks for these scenarios between 2006 (EPBD recast, Coop RR&WR Acc scenarios) and 2014 (reference scenario). EE level 1 still shows considerable shares in 2060 in the reference scenario. This is due to the assumption that the shares of EE level 1 and EE level 0 remain constant from 2008 in the reference scenario (see Section 5.3.1). In case of the other scenarios, EE level 1 phases out by around 2050.

When we look at the share of EE level 2 of the building stock, we see that – as we defined it – EE Boundary High and EE Boundary Low have 0 % of EE level 2 (Figure 16). For the other scenarios, EE level 2 has a share of around 6 % in the year 2000. EE level 2 shares are identical for all scenarios until 2006 (14 %). From 2007, the EPBD Recast, the Coop RR, Coop WR, and Coop RR&WR as well as the Coop RR&WR Acc scenarios deviate from the reference scenario. For these scenarios, the EE level 2 share shows a maximum value in 2017. Then, a decrease is observed until in year 2058 a share of 0 % is reached.

From 2010, also the Full Coop and Full Coop Acc scenarios deviate from the reference scenario as from 2009 a 100 % share of EE level 3 was assumed (see Section 8). Thus, the share of EE level 2 decreases from 2010 for the Full Coop and Full Coop Acc scenarios until in 2049 the whole building stock is composed of EE level 3.

Figure 17 shows the EE level 3 shares of the building stock according to the policy scenarios. The full cost optimal scenarios show an earlier phasing in of EE level 3 than the EPBD Recast and cost optimal scenarios. The full cost optimal scenarios reach 100 % EE level 3 building stock some years earlier (2049) compared to the EPBD Recast and cost optimal scenarios (2056).

[21] The same evolution of EE levels was assumed for all countries (see Chapter 8).

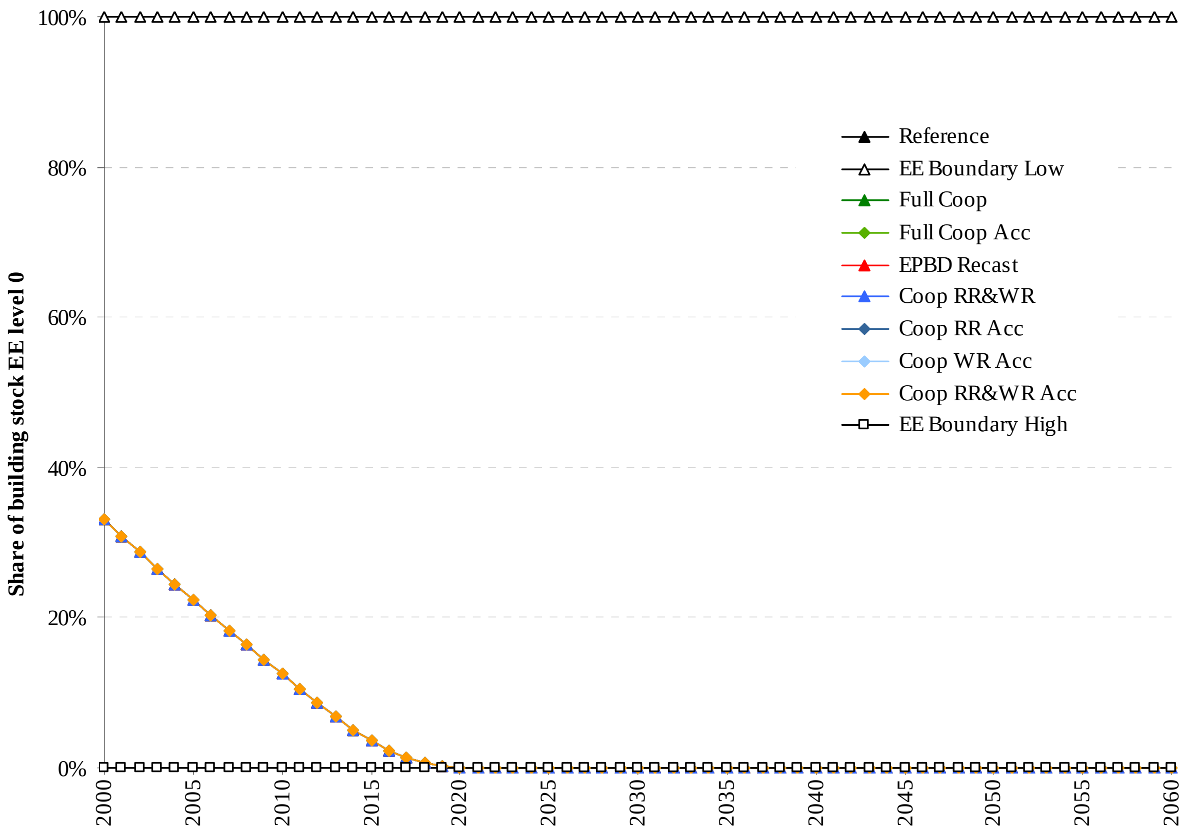

Figure 14 Relative share of EE level 0 of the building stock according to the policy scenarios

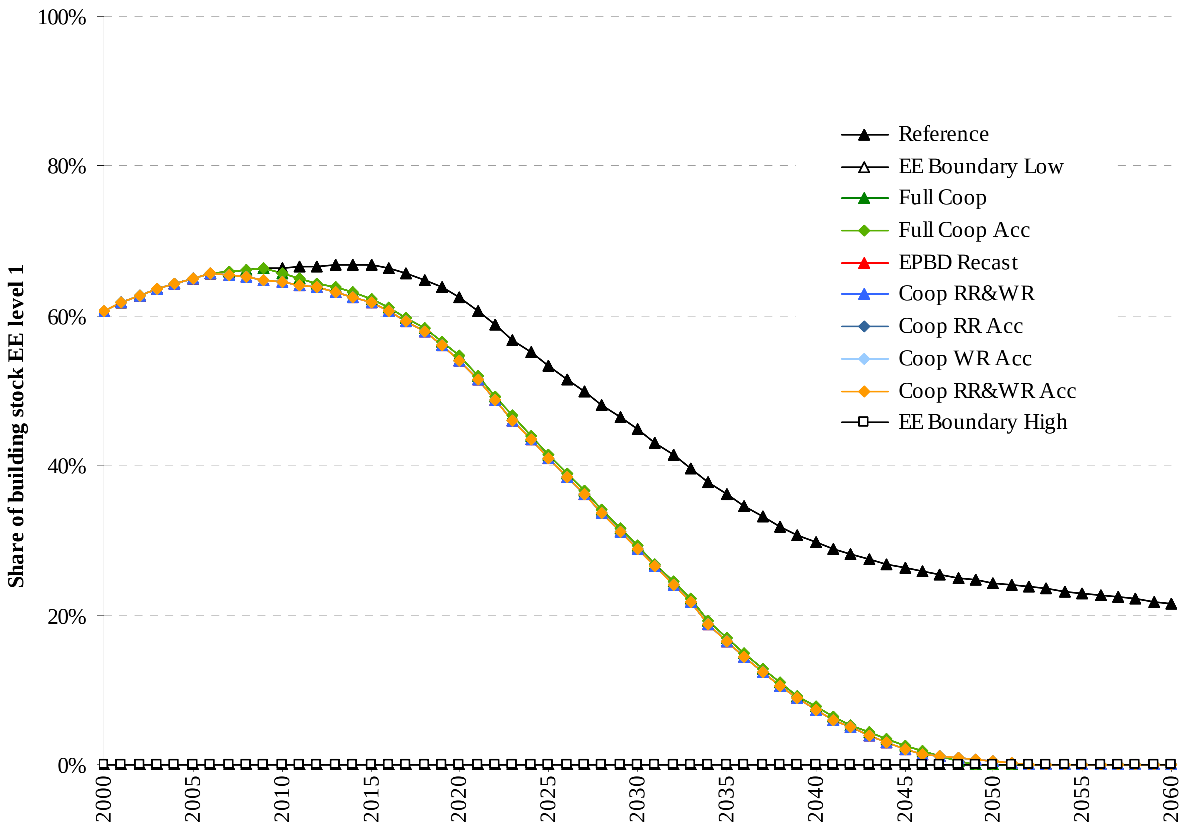

Figure 15 Relative share of EE level 1 of the building stock according to the policy scenarios

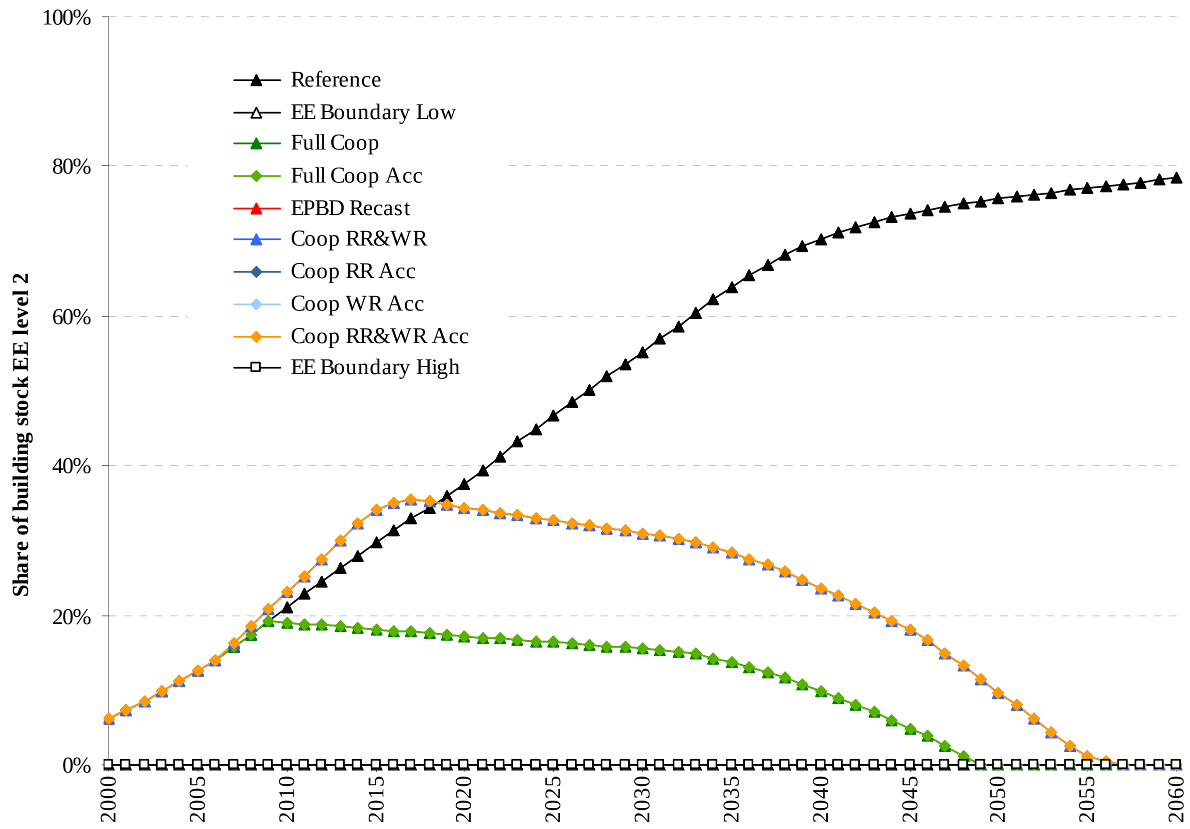

Figure 16 **Relative share of EE level 2 of the building stock according to the policy scenarios**

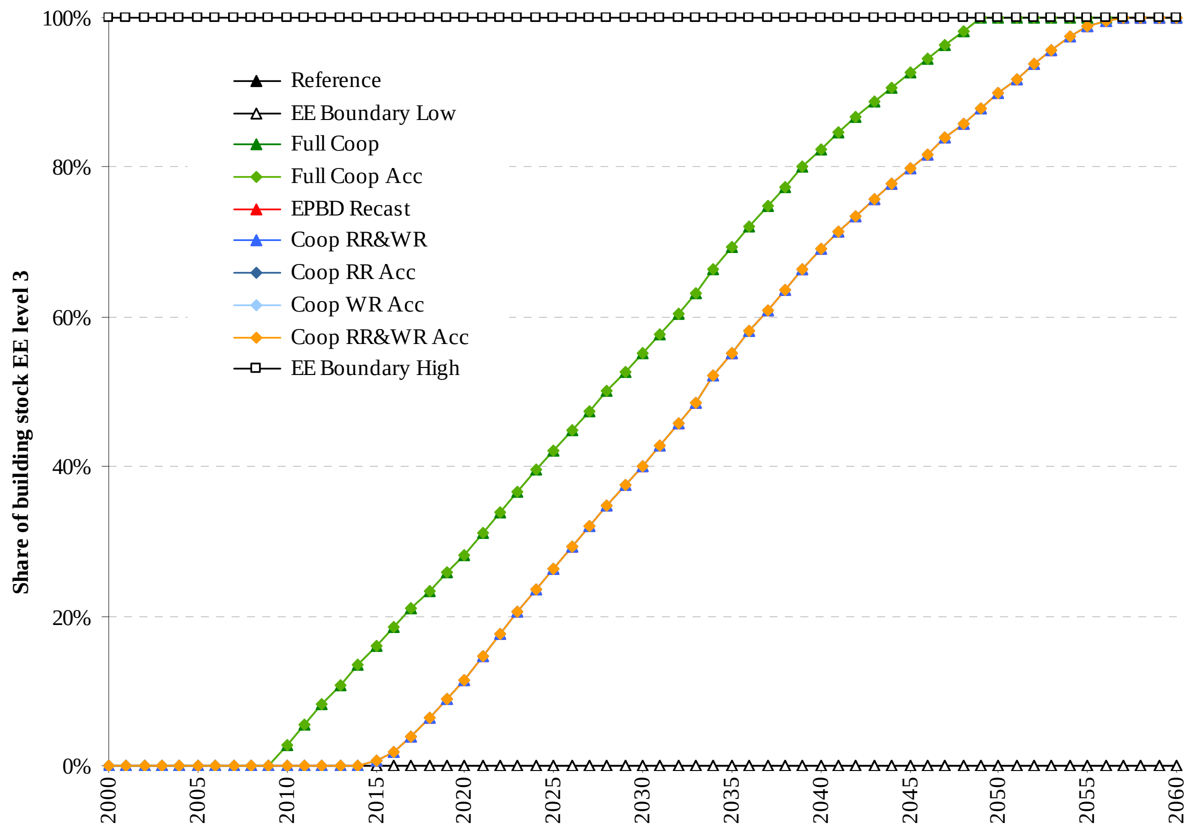

Figure 17 **Relative share of EE level 3 of the building stock according to the policy scenarios**

9.1.2 Major renovation activity

The total building stock that underlies major renovation is the same for all policy scenarios but differs between the countries due to different assumptions on the building stock development (construction and demolition activity) in the past (see Section 5.1). In Figure 18, the building stock that undergoes major renovation is depicted.

In Germany, clearly the peak in construction activity in the 1990s can be seen (compare Figure 4) which leads to an increase in major renovation 40 years later. The same applies to Poland where the increase between 2040 and 2045 can be attributed to higher building activity in 2000 to 2010. For Spain, no historical data for the building stock was available, thus no sudden peaks can be observed. The increases every 40 years results from the assumptions that had to be made for the starting years 1900 to 1940 (see Section 5.1).

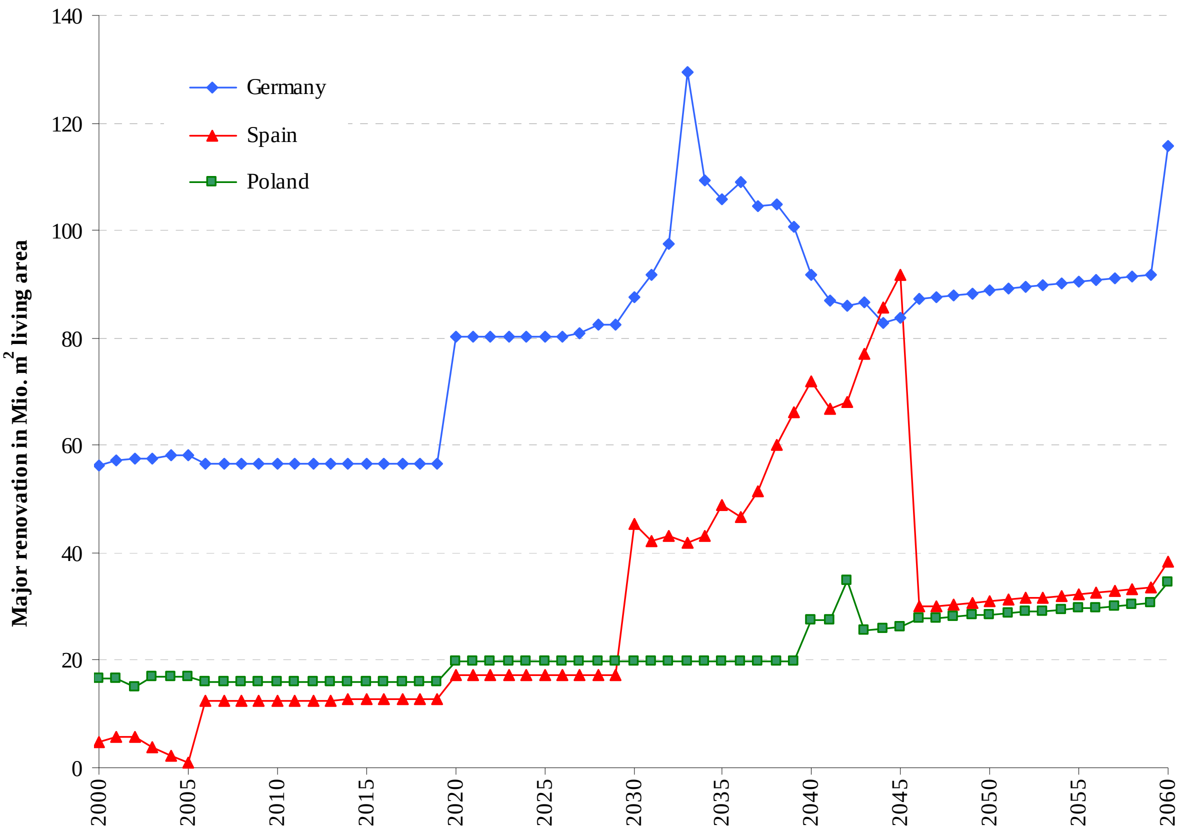

Figure 18 Major renovation activity according to country from 2000 to 2060

The major renovation activity can also be regarded with respect to the energy efficiency level – which then is different for the individual policy scenarios and follows the EE level development. As an example, Figure 19 shows the major renovation in Poland for the EPBD Recast scenario. Energy efficiency level 0 does not occur from 2000 on any more. Between 2000 and 2012, major renovations are performed according to EE level 1 and EE level 2 standards with decreasing share of EE level 1. From 2014 on, EE level 3 phases in and from 2018, all major renovations are accomplished in compliance with the cost optimal energy efficiency level.

The picture would be similar for the other cost optimal scenarios (e.g. Coop RR, Coop WR, Coop RR&WR) as can be seen from Figure 20. For the full cost optimal scenarios, the major renovations are performed according to EE level 3 from 2009 which leads to a faster EE improvement of the building stock (see Section 9.1.1).

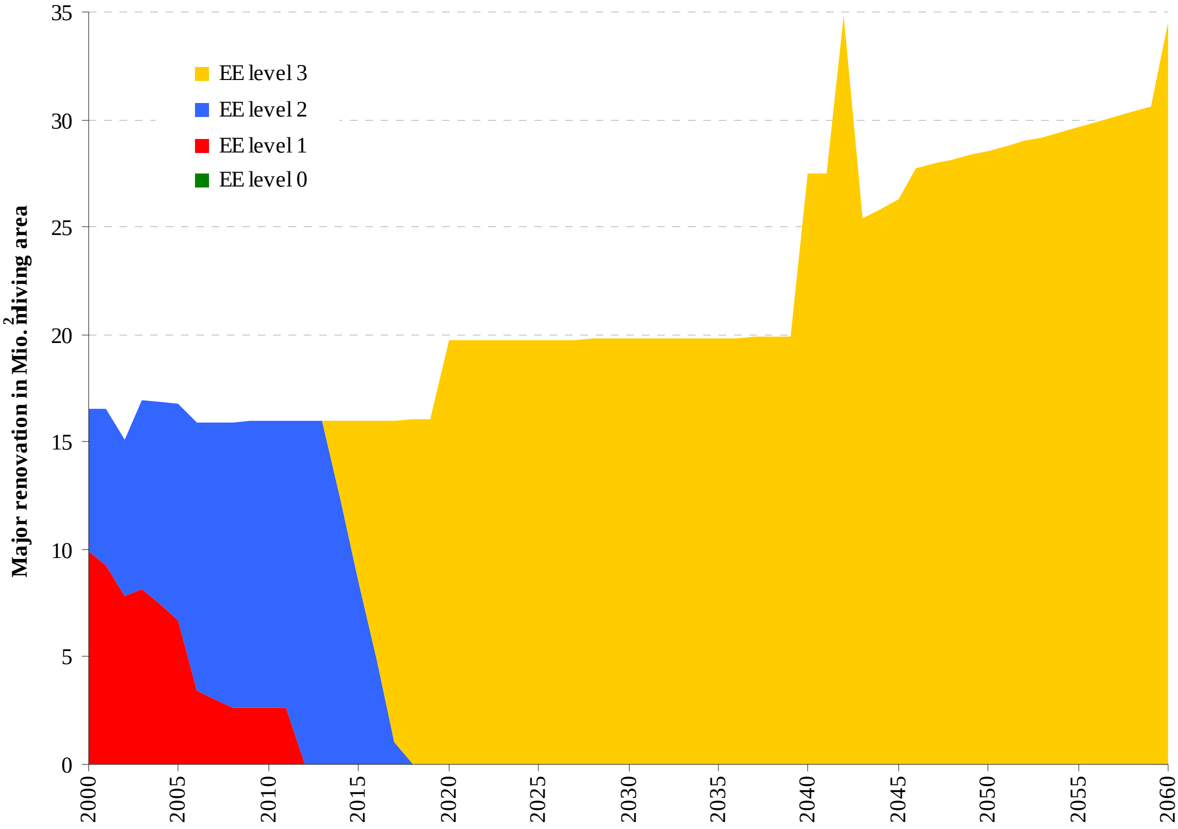

Figure 19 Major renovation activity for Poland according to EE level (EPBD Recast scenario)

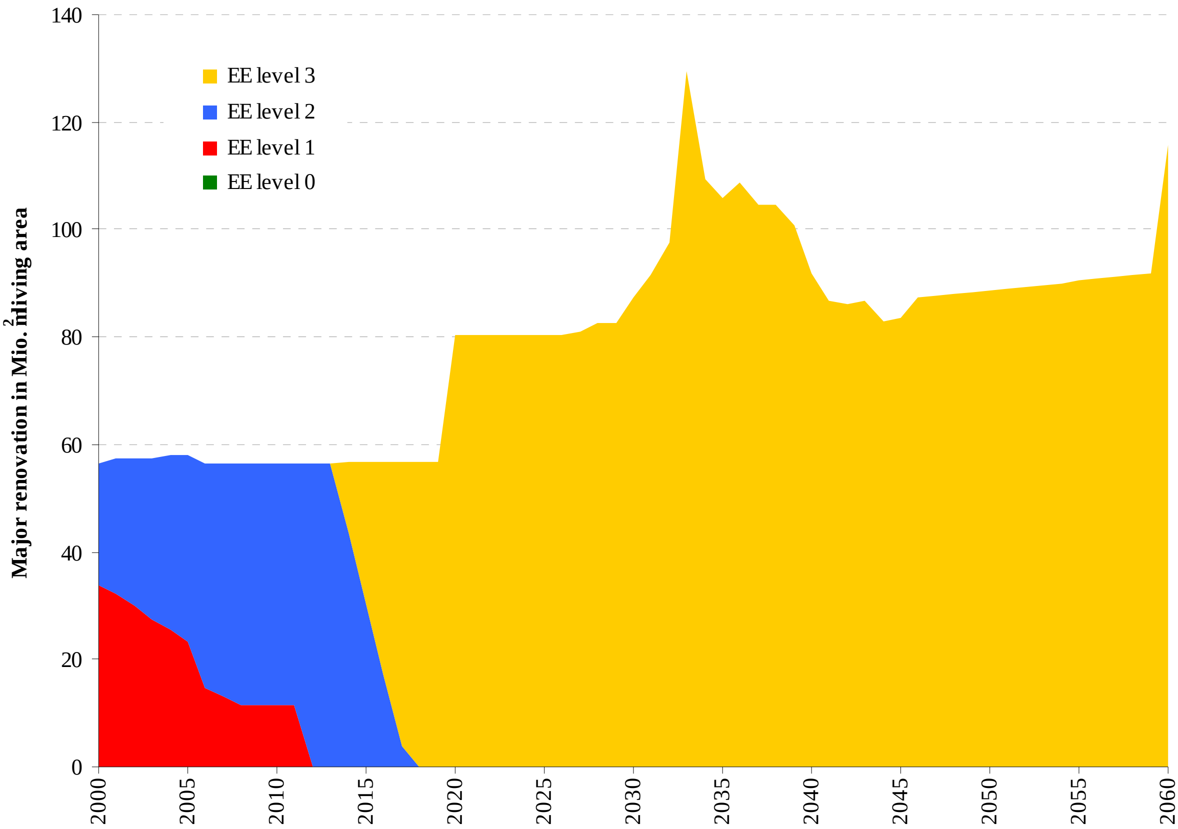

Figure 20 Major renovation activity for Germany according to EE level (Coop RR&WR scenario)

9.1.3 Roof refurbishment activity

The roof refurbishment shows similarities to the major renovation activity in the individual countries. However, the increase in construction in Germany in the 1990s now is reflected already in the 2010s compared to major renovation peaks in the 2030s due to the roof refurbishment cycle of 20 years compared to 40 years for major renovations (Figure 21). Total roof refurbishment in Germany is by far larger than in the other countries due to a much higher total building stock.

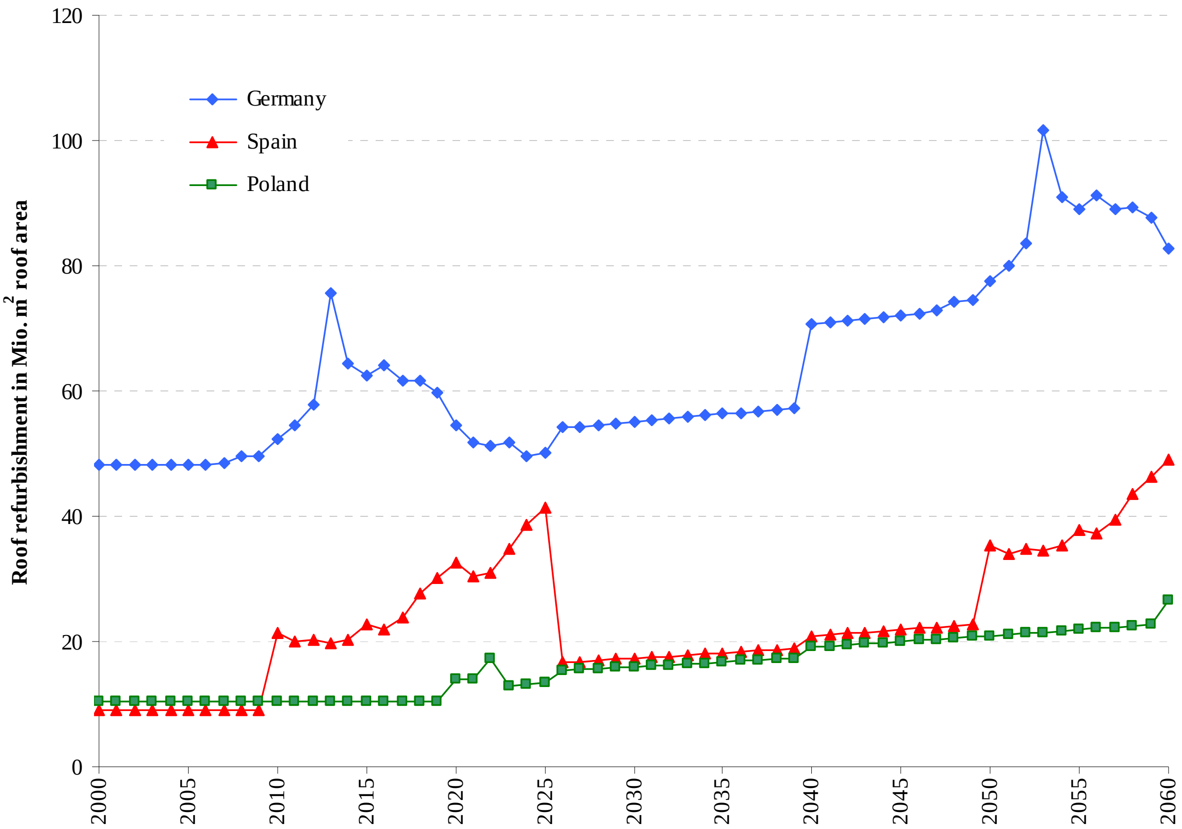

Figure 21 Roof refurbishment activity according to country from 2000 to 2060 for the reference scenario

Roof refurbishment area is subject to changes in the different scenarios when an acceleration of roof refurbishment is aimed at. This includes the three scenarios: Full Coop Acc, Coop RR Acc, and Coop RR&WR Acc (Figure 22). For the other scenarios, the roof refurbishment area is the same than in the reference scenario.

In the case of the Full Coop Acc scenario, the roof refurbishment is accelerated from 2009 to 2018. Within this period, it is assumed that roofs that have not yet fully completed their expected lifetime will also be refurbished. In fact, the refurbishment cycle is halved, i.e. roofs that are only 10 years old will already undergo refurbishment. Thus, after 10 years (in 2019) all roofs of the total building stock have been refurbished. For the subsequent 10 years, no roof refurbishment takes place while from 2029 on, the usual refurbishment cycle is in place again. From 2039, we see the same roof refurbishment activity than in the reference scenario.

Similarly, the Coop RR Acc and Coop RR&WR Acc scenarios show a significant increase in roof refurbishment when acceleration starts. For these scenarios, this was assumed to take place in 2014. Roof refurbishment is again driven down to zero between 2024 and 2033. From 2034, again an increase is to be seen (the 'echo' of the initial acceleration phase). From 2044, the roof refurbishment is equal to the reference scenario again. The pattern thus is the same than for the Full Coop Acc scenario but delayed by five years.

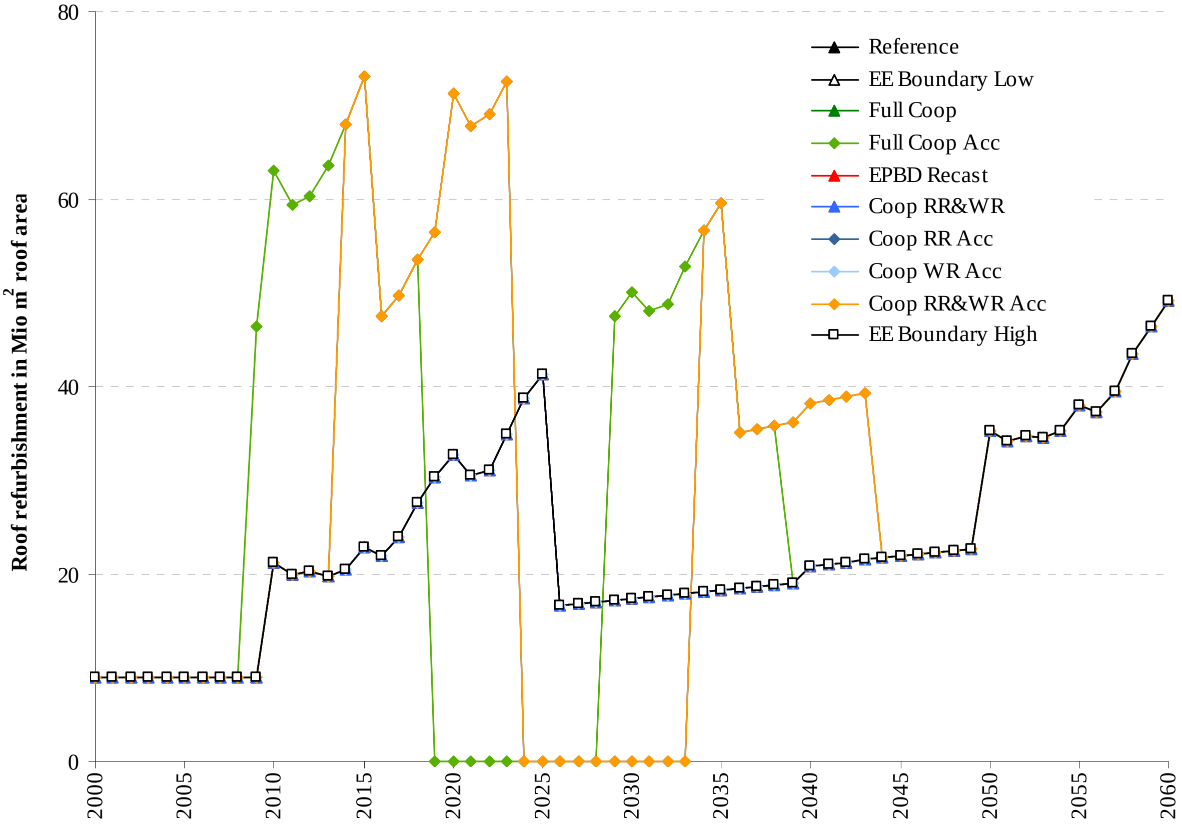

Figure 22 Roof refurbishment activity according to policy scenario for Spain

9.1.4 Window refurbishment activity

Window refurbishment is similar to roof refurbishment due to the same refurbishment cycle length of 20 years. Only the absolute values differ because the ratios of roof:living area and window:living area are not the same. Figure 23 shows the window refurbishment in the reference scenario for all the three countries. Again, we can see the peak shift of 20 years as in the case of roof refurbishment.

The window refurbishment activity differs according to policy scenarios (Figure 24). The three accelerated scenarios (Full Coop Acc, Coop WR Acc, and Coop RR&WR Acc) show a different pattern compared to the other scenarios which are the same than the reference scenario.

In the Full Coop Acc scenario, window refurbishment is accelerated from 2009 to 2018 (as it is the case for the roof refurbishment). In 2019, all windows of the total building stock have been refurbished. Thus, for the subsequent 10 years, no window refurbishment takes place. From 2029 on, the usual refurbishment cycle applies again. From 2039, the window refurbishment is the same than in the reference scenario.

Similarly, the Coop WR Acc and Coop RR&WR Acc scenarios show a significant increase in window refurbishment from 2014. The refurbishment is zero between 2024 and 2033. From 2034, again the initial refurbishment cycle is assumed. The window refurbishment is the same then for the reference scenario from 2044 – similar to the roof refurbishment acceleration (see Section 9.1.3). The pattern thus is the same than for the Full Coop Acc scenario but delayed by five years.

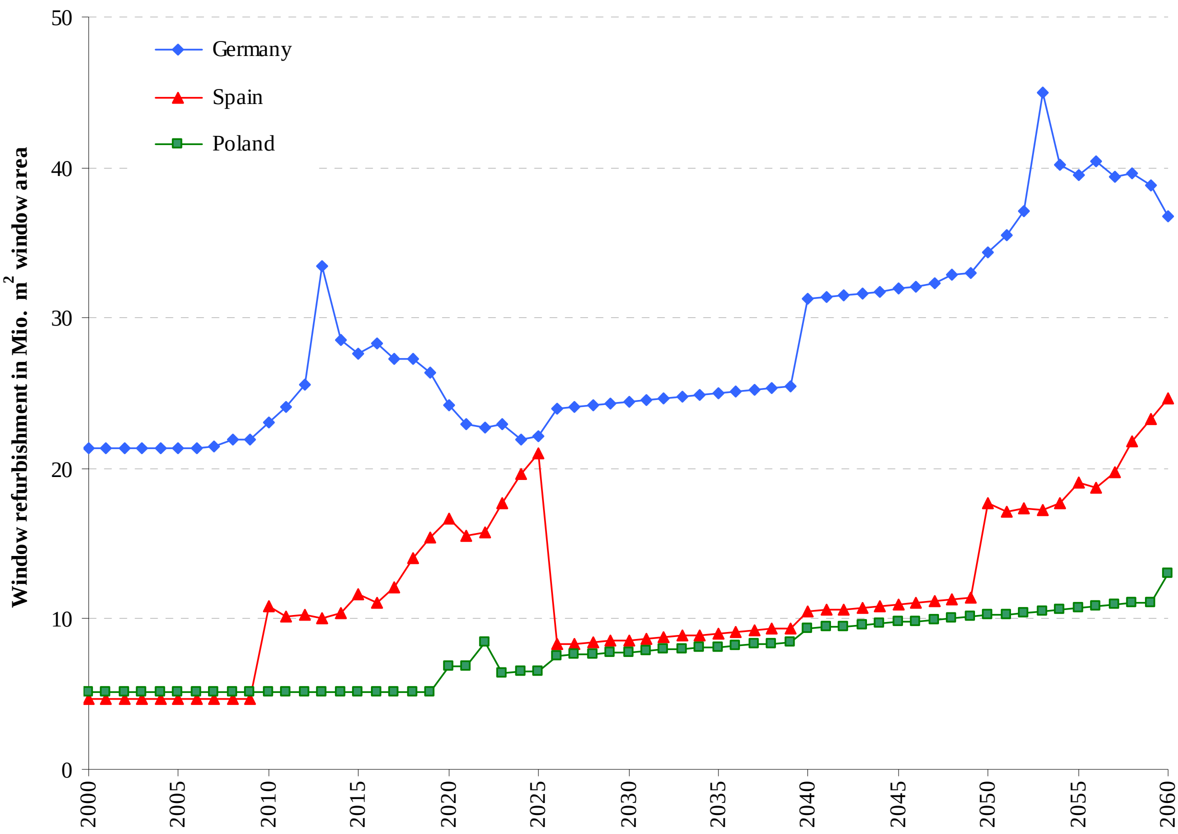

Figure 23 Window refurbishment activity according to country from 2000 to 2060 for the reference scenario

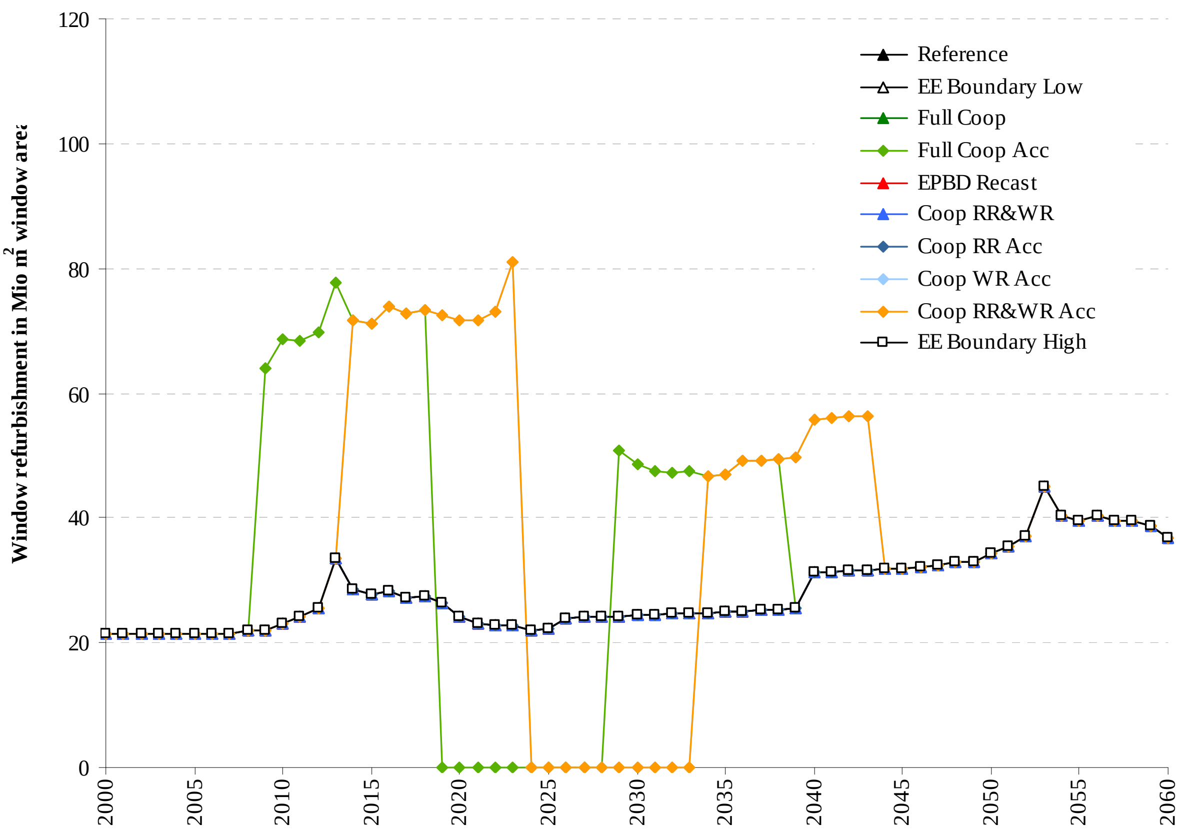

Figure 24 Window refurbishment activity according to policy scenario for Germany

9.1.5 Energy demand

From the building stock model, the energy demand for space heating is calculated (see Sections 5.3 and 6.2). The energy demand in the reference scenario is shown in Figure 25 for the three countries. There can be seen a small drop in energy demand first which is due to the upgrading of the building stock to energy efficiency level 2 (see Section 5.3.1). As the energy efficiency level distribution is kept constant from 2008, the energy savings are outweighed by the increase in total building stock (see Section 5.1). As the annual building stock increase is higher for Poland than for Spain and Germany, the energy savings are compensated earlier. In Germany, only a small annual increase was assumed, thus, the energy savings are compensated only from the 2050s on by the increased building stock.

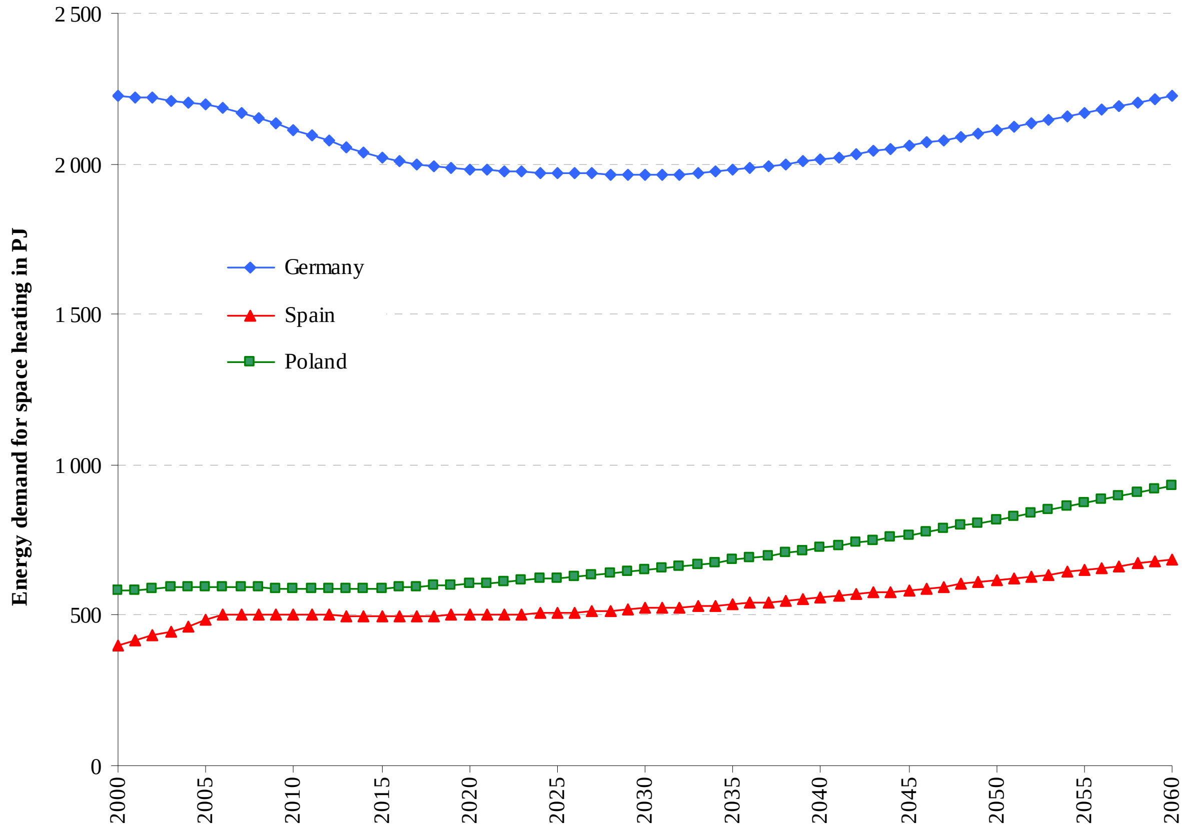

Figure 25 Energy demand for space heating according to country from 2000 to 2060 for the reference scenario

The energy demand for space heating in Germany is displayed in Figure 26 for the policy scenarios analysed. The EE Boundary Low and EE Boundary High scenarios show the theoretical minimum and maximum range of the energy demand.

The energy demand of the other scenarios follows the reference scenario from 2000 and then, due to improved energy efficiency of the building stock, approaches the EE Boundary High scenario. By around 2050, the energy demand of the EE Boundary High scenario is reached (the total building stock is upgraded to cost optimal EE levels then).

As expected, the EPBD recast scenario shows the highest energy demand compared to the other policy scenarios (Full Coop, Coop RR/WR scenarios) as it is used as a basis for additional policies (e.g. cost optimal roof refurbishment). Apparently, the full cost optimal scenario shows lowest energy demand compared to the other scenarios.

The calculated energy demand for space heating in the reference scenario shows good accordance with official statistics. For example, in the year 2000, the calculated energy demand for Germany amounts to 2 220 PJ while statistics give a value of 2 120 PJ [Destatis 2008].

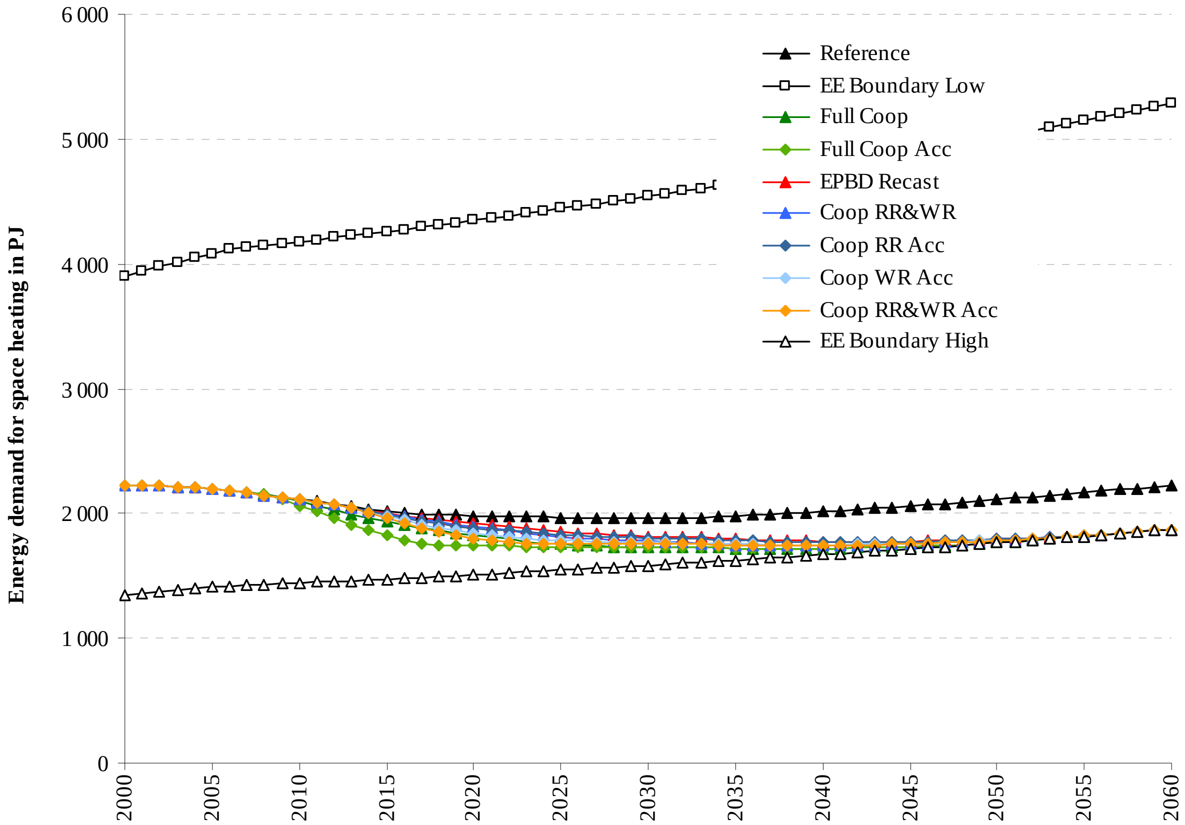

Figure 26 Energy demand for space heating according to policy scenario for Germany

The energy demand calculations for Spain and Poland are similar to the results for Germany (Figure 27 and Figure 28).

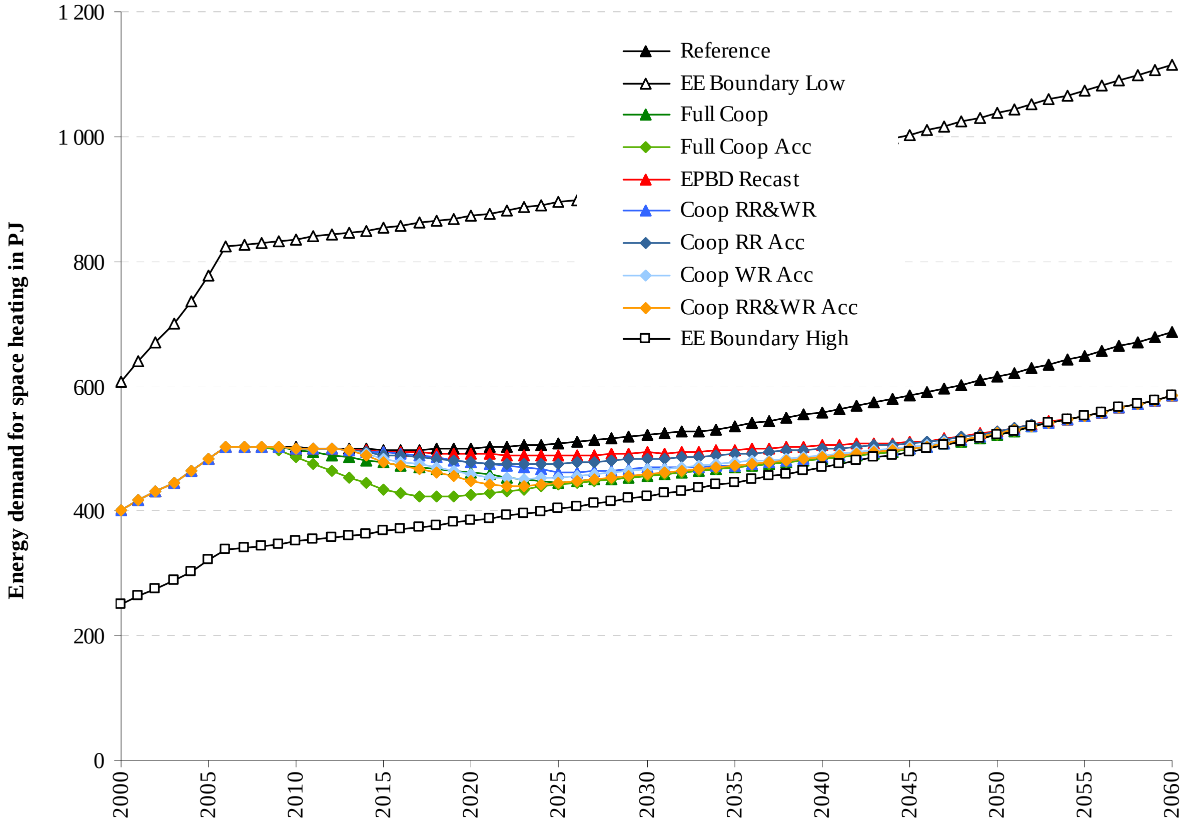

Figure 27 Energy demand for space heating according to policy scenario for Spain

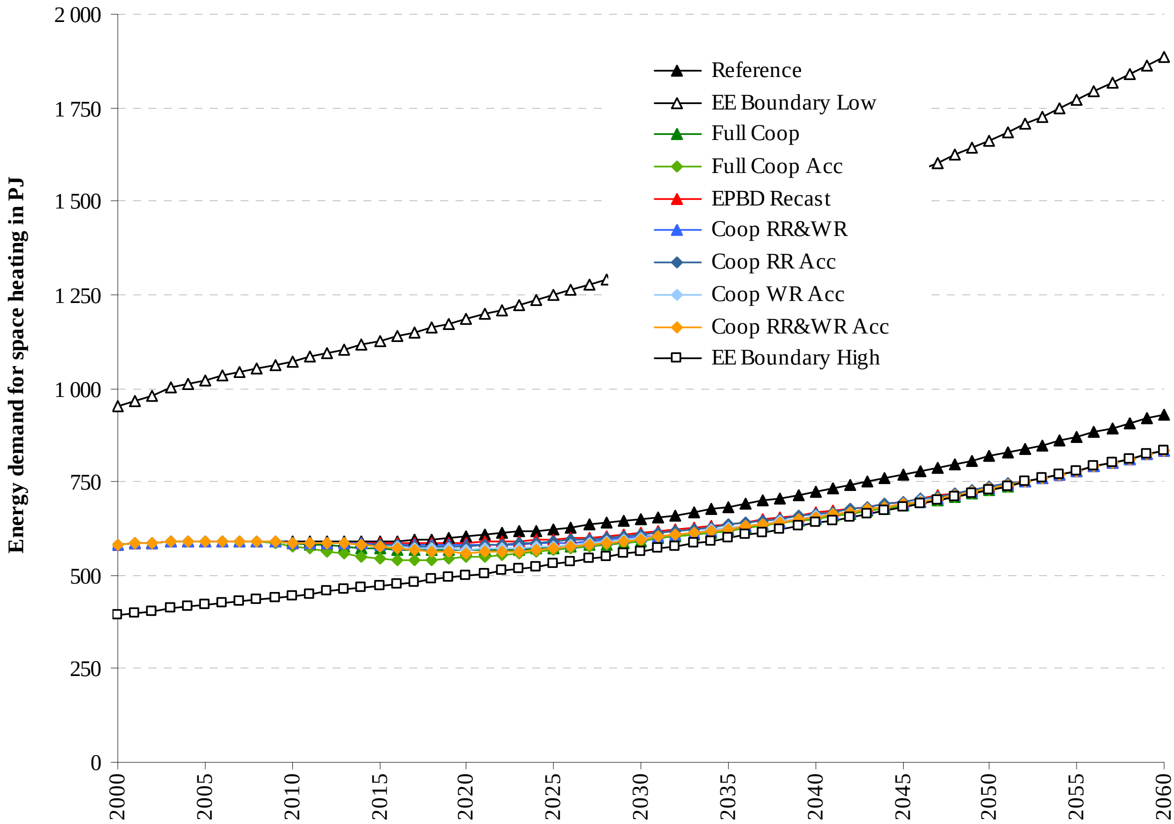

Figure 28 Energy demand for space heating according to policy scenario for Poland

9.1.6 Greenhouse gas emissions from households

The greenhouse gas emissions due to space heating from private households were calculated following the methodology described in Section 6.3. The pattern of GHG emissions follows the energy demand according to the policy scenario. Figure 29 shows the greenhouse gas emissions due to space heating for Germany as an example.

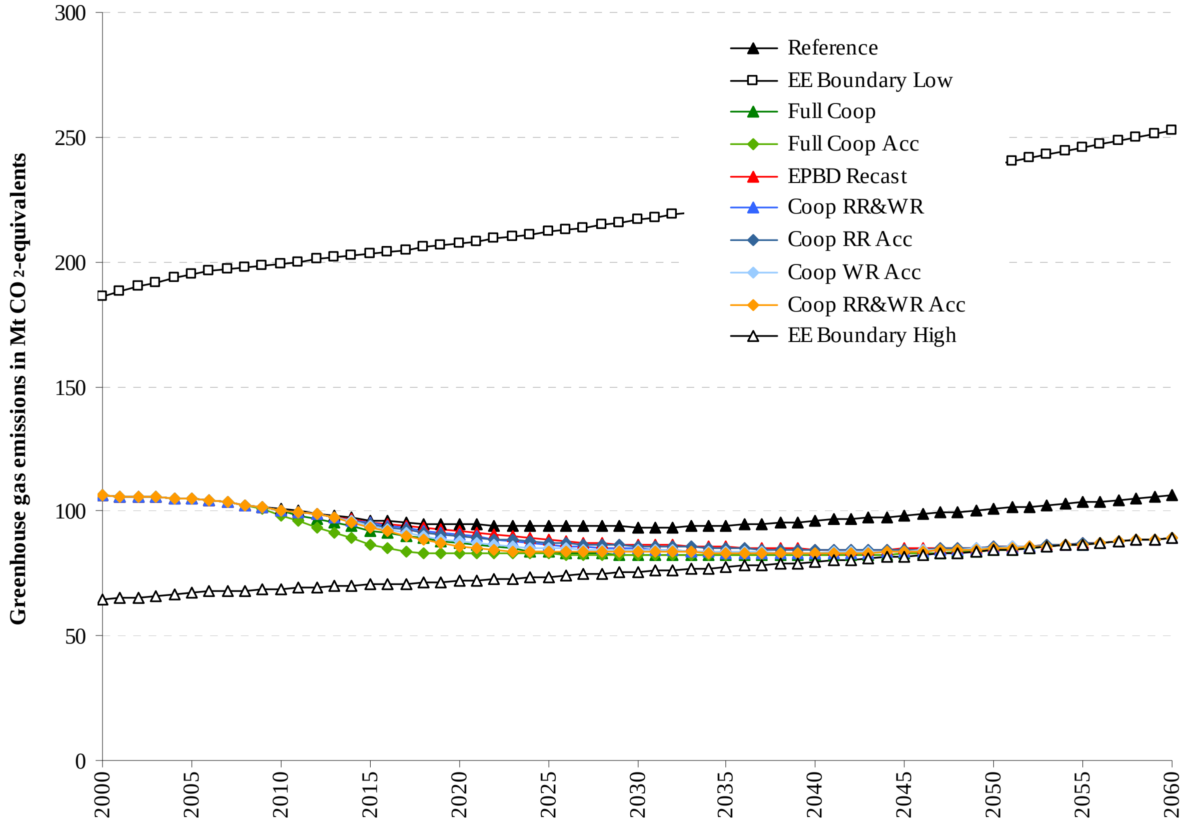

Figure 29 GHG emissions due to space heating according to policy scenario for Germany

The cumulative greenhouse gas emission savings from 2000 to 2060 is shown in Table 37. The highest savings are achieved by the Full Coop Acc scenario, followed by the Full Coop and the Coop Acc RR&WR scenario for all countries. The relative savings of GHG emissions range between 5.9 % and 11.5 % compared to the reference scenario depending on country and policy scenario – without including the EE Boundary High and Low scenarios (Figure 30).

Table 37 Total greenhouse gas emission savings according to policy scenario and country from 2000 to 2060

Country	Reference	EE Boundary High	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR	EE Boundary Low
	Mt CO_2-equivalents									
Germany	0	1 371	594	655	458	514	485	537	564	-7 294
Poland	0	232	109	119	87	98	91	101	106	-1 429
Spain	0	283	138	157	97	122	108	128	137	-951

The relative greenhouse gas emission savings are highest for Spain, followed by Germany and Poland, in general. For two scenarios, the relative savings are higher in Germany compared to Spain: the EPBD recast, and the Coop Acc RR scenarios.

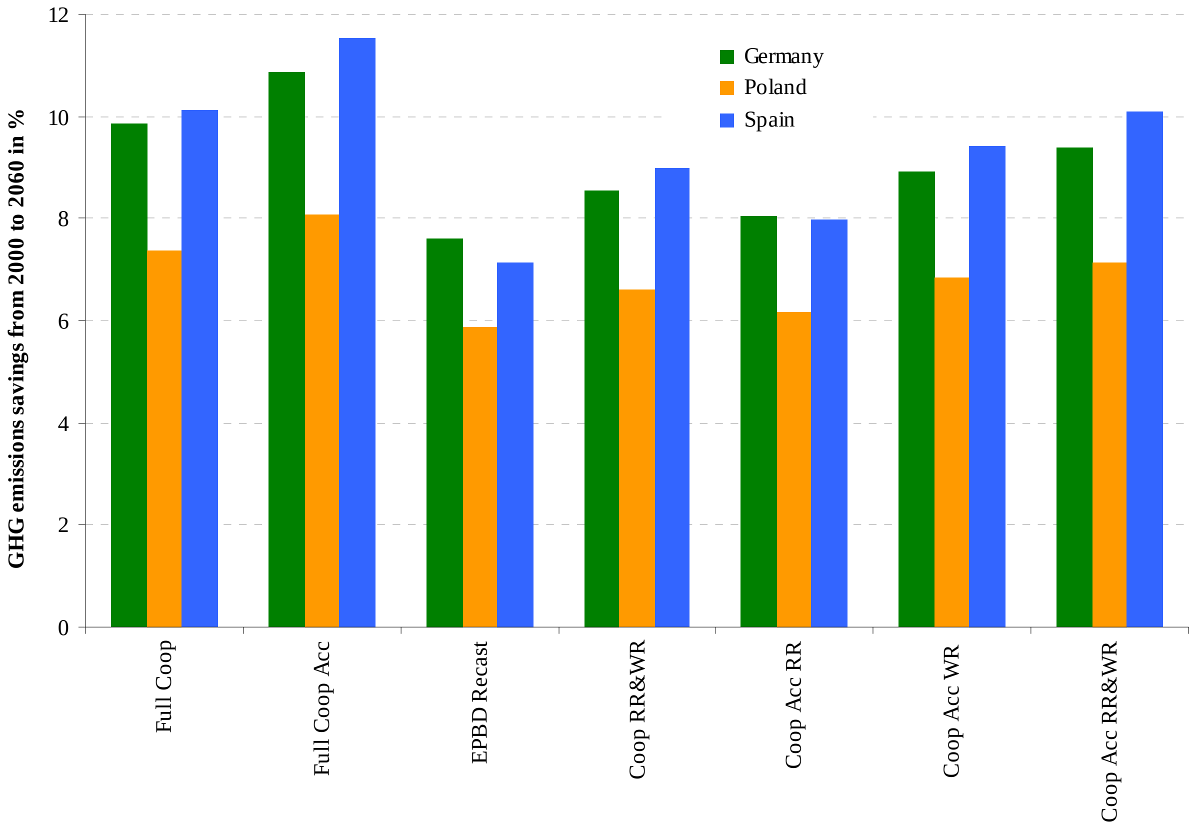

Figure 30 Relative GHG emission savings (households) from 2000 to 2060 compared to the reference scenario

The differences between the countries are due to the historical development of the building stock and the initial energy efficiency level of the building stock which determines renovation and refurbishment activity as well as energy efficiency improvement potential. Also the share of the different building types (single-family, multi-family, high-rise) influences the results. In addition, the climatic conditions play a major role in explaining the country differences as they are a major factor explaining the initial energy demand for space heating.

9.1.7 Cost composition for households

The composition of the costs of households for the construction of new buildings, renovation and refurbishment activities, as well as energy costs for space heating can be derived from the building stock model. Figure 31 shows the household expenditures according to policy scenario in Spain for the years 2015 and 2025. As mentioned before, the construction costs are the same for all policy scenarios but differ only between the years (see Section 6.1.4). The construction costs make up the greatest share of costs. In our example, the share of construction costs range from 74 % to 88 % according to year and scenario. For the three countries, all years, and all scenarios, the share ranges from 43 % to 96 %.

Also, for major renovation, the expenditures doe not differ much between the single scenarios because the building area that undergoes major renovation is the same for all scenarios (see Section 9.1.2). The differences between the scenarios result only from the different costs of major renovation according to EE level. Thus, the EE Boundary Low scenario always shows slightly smaller major renovation costs due to the fact, that only EE level 0 is applied in this scenario. The other scenarios show values close to the EE Boundary High scenario (always EE level 3). The share for major renovation ranges from 2.2 % to 3.8 % in our example for Spain.

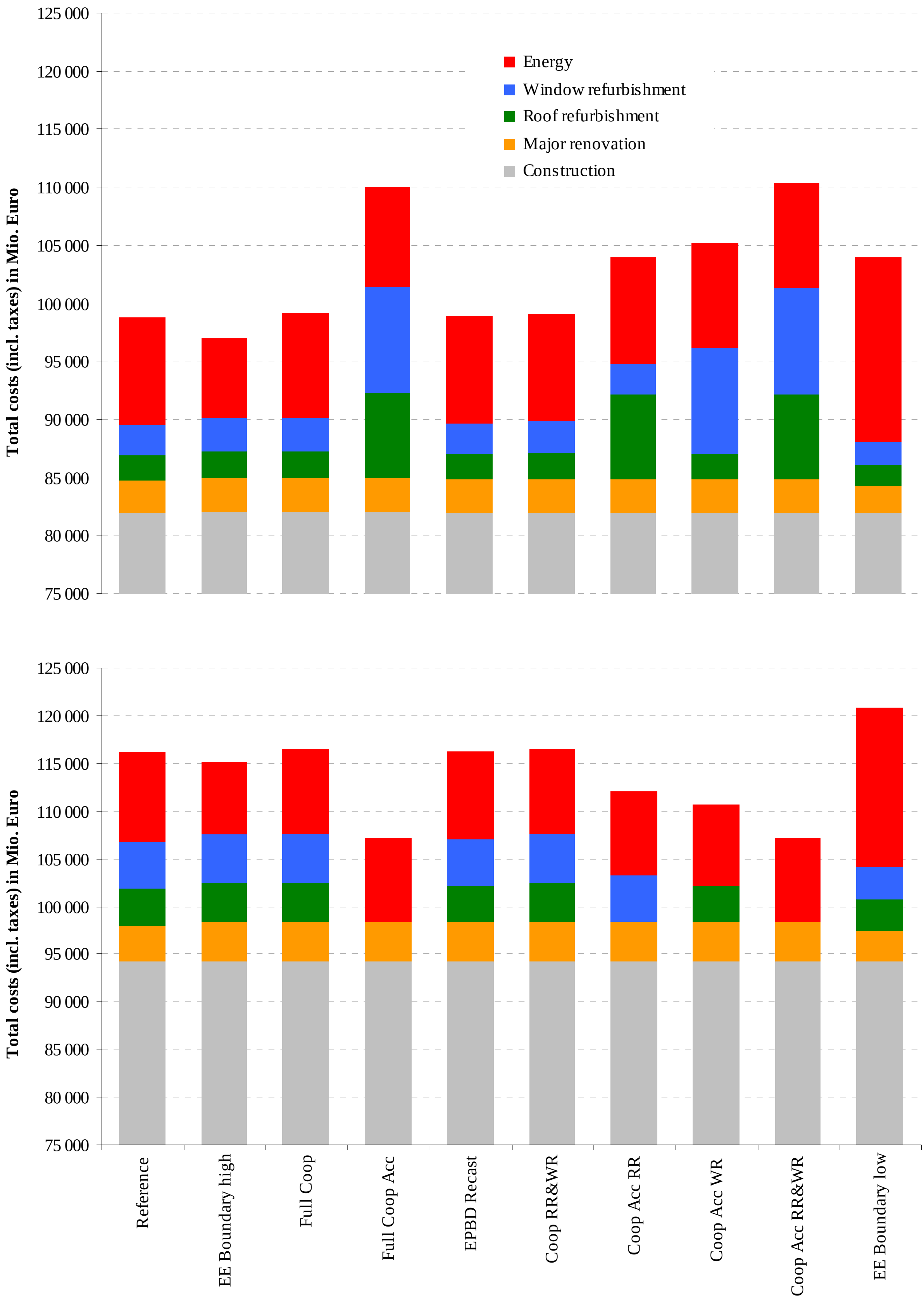

Figure 31 Cost composition for households in the year 2015 (top) and 2025 (bottom) in Spain

Major variations can be found for the costs of building element refurbishment and energy. The costs for roof and window refurbishment can be significantly greater in the accelerated scenarios during the acceleration period (e.g. in 2015) and considerably smaller (zero) in the subsequent years (e.g. 2025).

Energy costs vary much between the scenarios. The EE Boundary High and EE Boundary Low scenarios represent the boundary values for energy costs. Energy costs constitute between 6.5 % and 15.3 % according to scenario in Spain for the years 2015 and 2025.

9.1.8 Net costs

The net costs – the additional expenditure for refurbishment or renovation minus the saved energy costs – for households (which includes all taxes) have been calculated for all policy options. As expected, the theoretical EE Boundary low scenario leads to higher net costs compared to the reference scenario due to overall higher energy costs that by far outweigh the lower costs for renovation and refurbishment in all countries (Figure 32 to Figure 34). For the EE Boundary High scenario, the net costs are negative which implies that the additional costs to reach a higher energy efficiency level are offset by the energy savings. All scenarios (except for the EE Boundary Low scenario) converge to the EE Boundary High scenario in between 2050 to 2060.

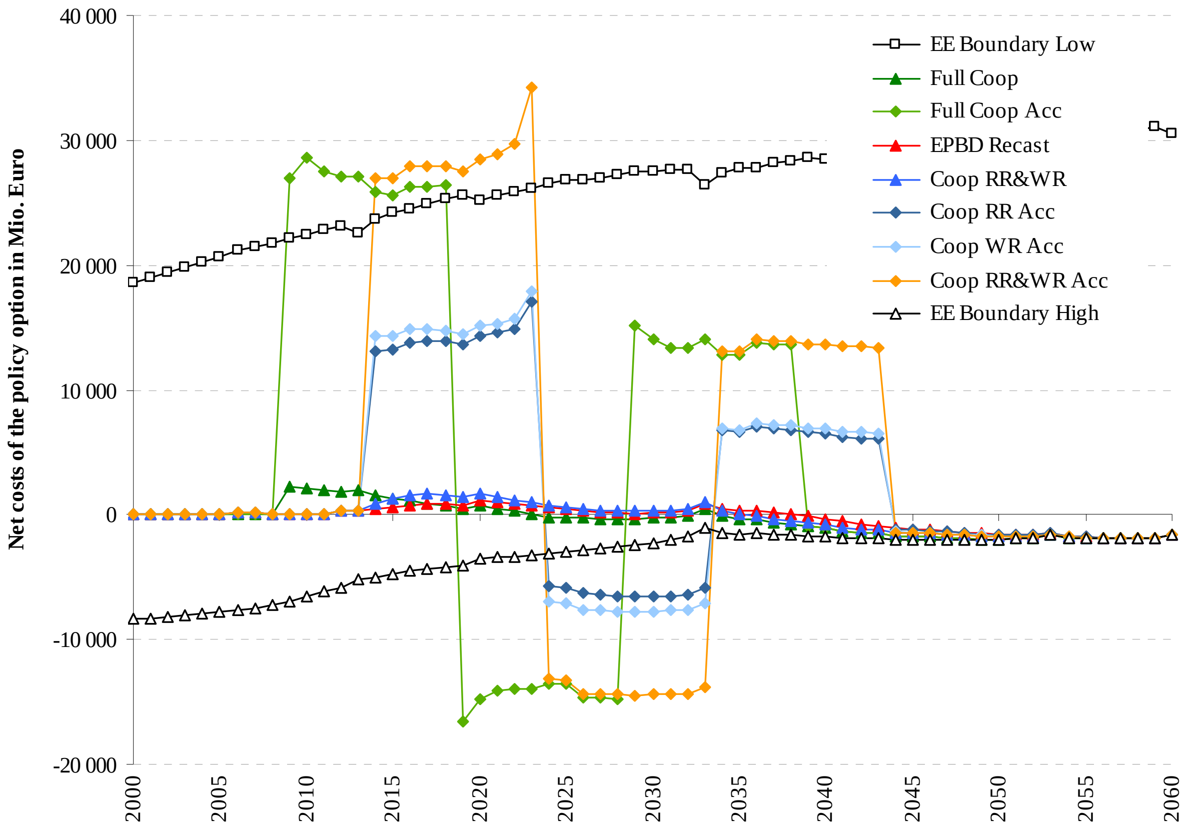

Figure 32 Net costs according to policy scenario from 2000 to 2060 for Germany

The EPBD recast scenario leads to higher net cost first (the energy savings do not offset the higher costs for renovation and refurbishment). At some point, the break-even is reached with energy cost savings equalising the additional the renovation and refurbishment costs. In Germany, this point is around 2040. In Spain this point is reached only in about 2045 while in Poland, the break-even is around 2027.

The full cost optimal scenario (Full Coop) initially leads to higher net costs compared to the EPBD recast scenario. In Germany and Poland, the break-even is reached earlier than in the EPBD recast scenario. In Spain, the break-even is at the same time. In general, the net costs – both the additional net costs in the beginning as well as the saved costs after the break-even is reached – are higher compared to the EPBD recast scenario.

The Coop RR&WR scenario is the same than the EPBD recast scenario up to 2013. From 2014, the net costs are higher than in the EPBD recast scenario due to higher costs for roof and window refurbishment as a higher EE level for roof and window refurbishment was assumed from 2014 compared to the EPBD recast scenario (see Section 8.6). Break-even is reached a bit earlier than in the EPBD recast scenario in Germany, in the same year in Spain and a bit later in Poland. This is explained by a different ratio of additional costs to energy savings in the individual countries and also due to a different development of the building stock which leads to different refurbishment patterns (whether a high share of building elements have to be refurbished in the time span the policy measure differs from the EPBD recast scenario, i.e. from 2014).

As it is the case of the Full Coop scenario, the range of the net costs is higher than for the EPBD recast scenario.

The accelerated scenarios (Full Coop Acc, Coop RR Acc, Coop WR Acc, and Coop RR&WR Acc) show a very different picture from the other scenarios. During the period with accelerated building element refurbishment, a high net cost results due to high additional expenditure for refurbishment measures. The ten years following the acceleration period, the net costs are significantly lower than for the reference scenario (and also the non-accelerated scenarios). This is due to the fact that no building element refurbishment occurs in this period (see Figure 22 and Figure 24).

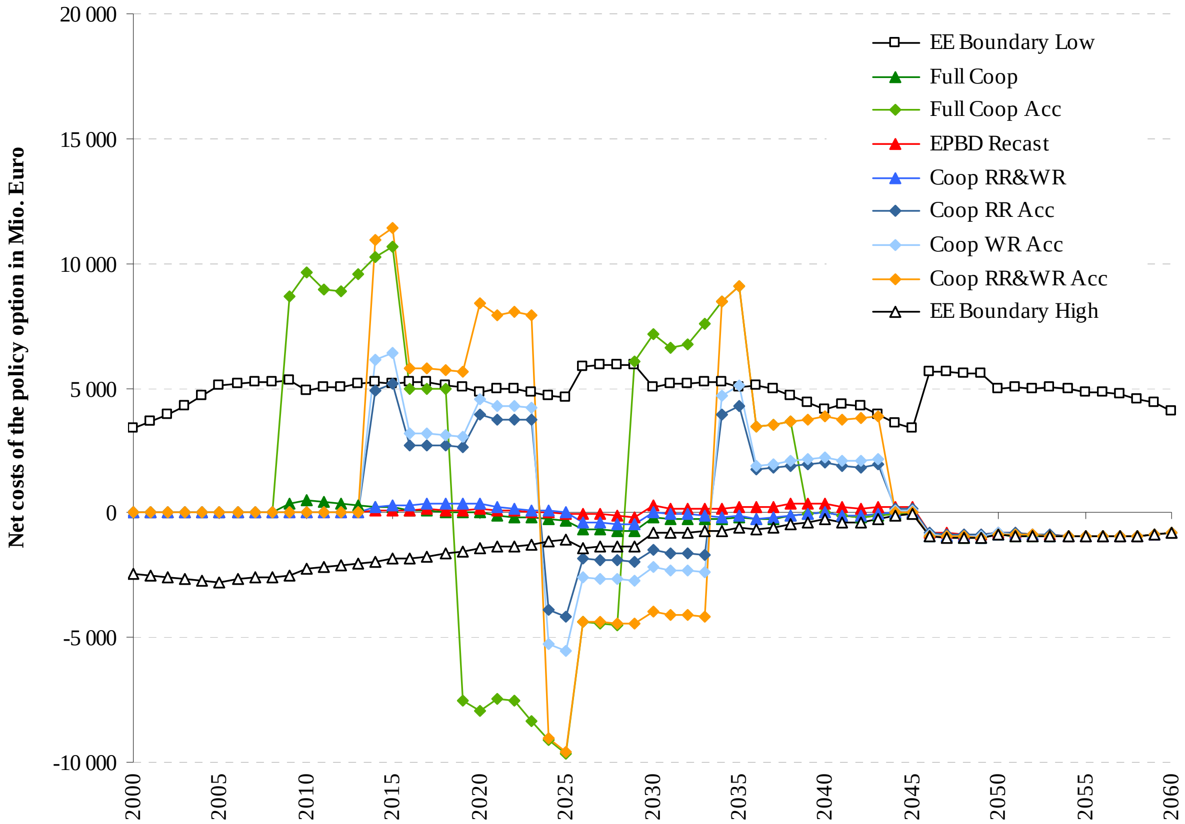

Figure 33 **Net costs according to policy scenario from 2000 to 2060 for Spain**

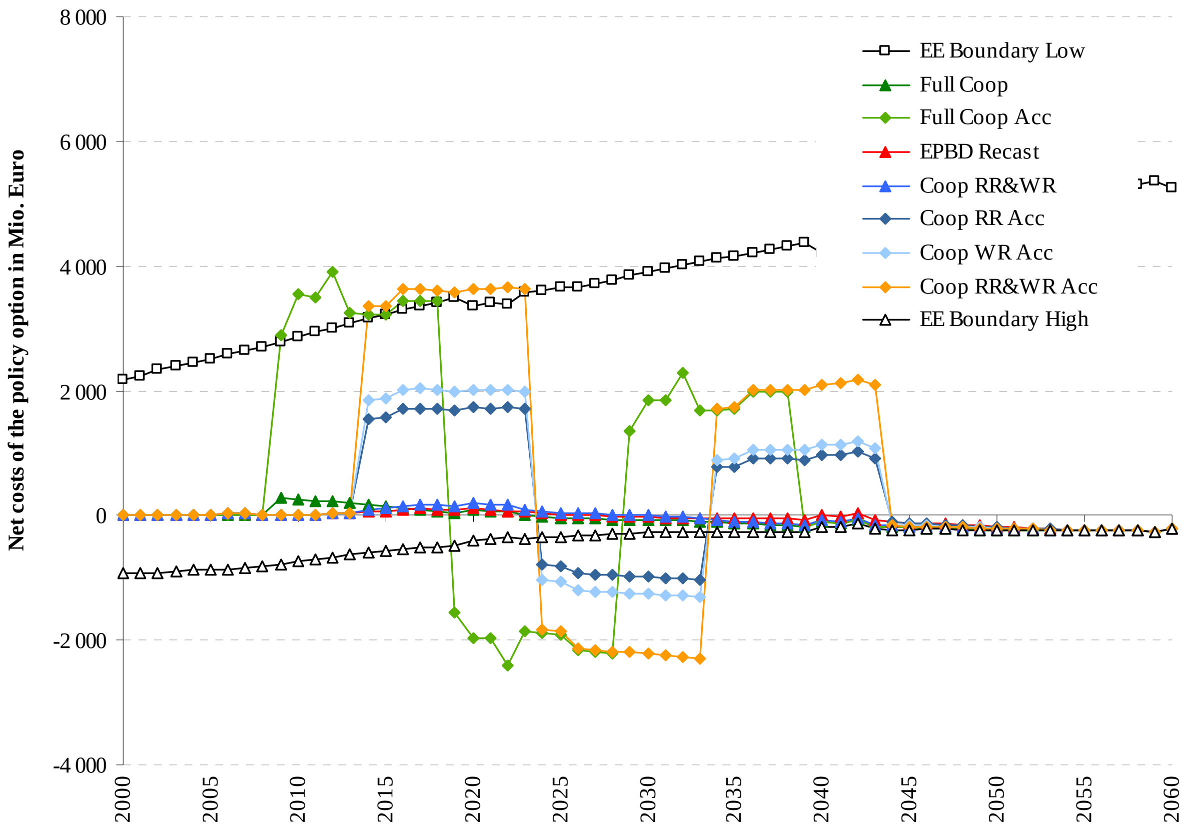

Figure 34 Net costs according to policy scenario from 2000 to 2060 for Poland

The cumulative net costs according to policy scenario and country from 2000 to 2060 is displayed in Table 38. As expected, the theoretical EE Boundary High scenario leads to lowest net costs (negative net costs for all years) while the EE Boundary Low scenario shows highest net costs.

For all three countries, the best policy scenario in terms of total net costs is the full cost optimal scenario (Full Coop). In Germany, the EPBD recast scenario is the next best, followed by the Coop RR&WR scenario. For Poland, and Spain, the Coop RR&WR scenario is slightly better than the EPBD recast scenario.

In all three countries, the accelerated scenarios lead to positive cumulative net costs (i.e. the energy cost savings do not offset the additional expenditures for renovation and refurbishment) from a household perspective.

Table 38 Cumulative net costs according to policy scenario and country from 2000 to 2060 in Mio. Euro

Country	Reference	EE Boundary High	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR	EE Boundary Low
Germany	0	-214 843	-23 230	222 397	-15 471	-14 547	119 602	118 443	253 565	1 611 003
Poland	0	-25 519	-3 670	27 626	-2 787	-2 829	13 274	14 815	30 871	234 719
Spain	0	-80 241	-17 356	58 631	-8 326	-13 462	24 675	25 131	59 054	298 676

9.2 Input-output model results

The input-output model was used to assess the impacts of the policy scenarios on the whole economy (see Chapter 7). The parameters analysed include value added, employment, compensation of employees, greenhouse gas emissions from the total economy (w/o household emissions), and welfare effects. The results of the IO analysis will be presented for each of these parameters in the following sections.

The IO model can be used not only to analyse the effects of the policies on the whole economy but also to evaluate the impacts on single sectors of the economy. The results of these investigations are taken into account when the individual policy scenarios are presented in detail (Section 9.3).

The results of the input-output model analysis will be presented in the following only for the policy scenarios except for the theoretical 'what-if' scenarios (EE Boundary Low and EE Boundary high) to enhance readability.

9.2.1 Value added

The results of the input-output model calculations for value added compared to the reference scenario are shown in Figure 35 as an example for financing option 1 and Germany. The value added effects are always positive and the value added is higher than in the reference for all scenarios.

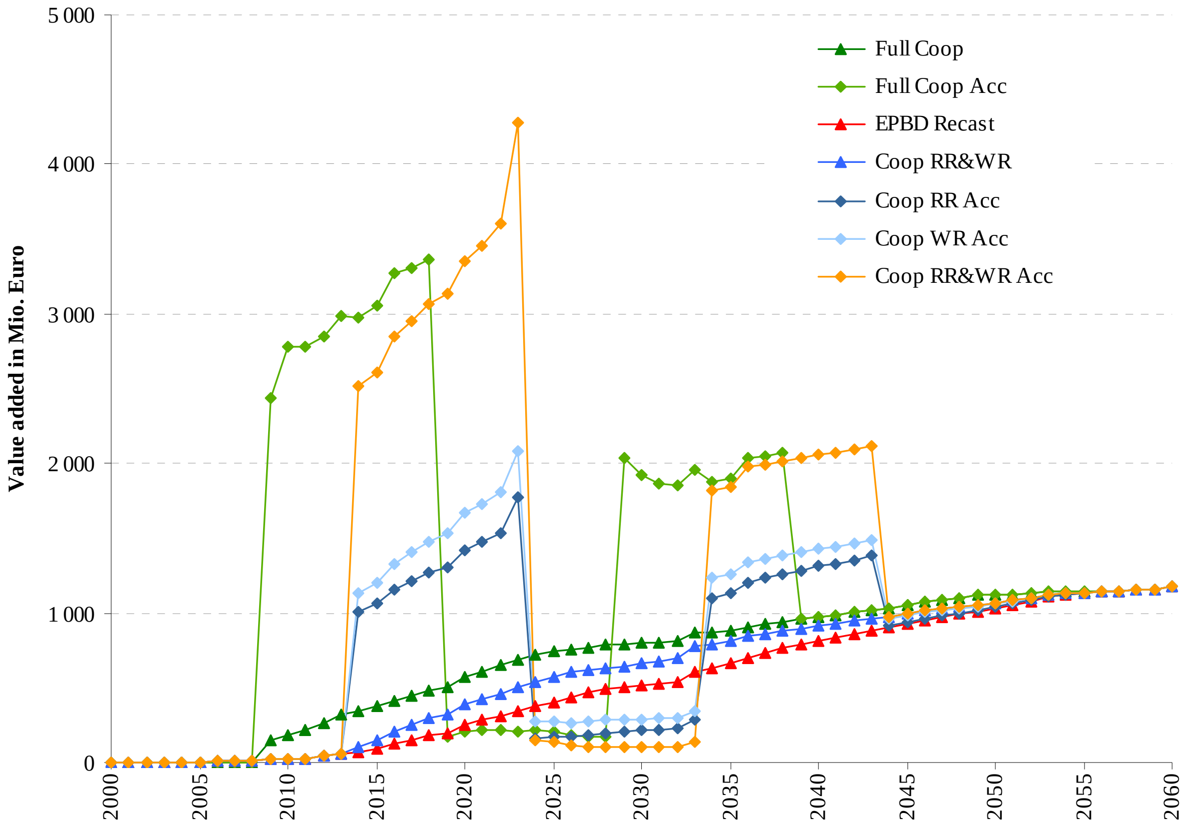

Figure 35 Value added according to policy scenario from 2000 to 2060 compared to the reference scenario for Germany (financing option 1)

Clearly, the accelerated scenarios show a great impact on value added during the acceleration periods (2009 to 2018 for the Full Coop Acc scenario, and 2014 to 2023 for the other accelerated scenarios).

Increased investment leads to sharp increase in value added in these periods. Interestingly, value added is not lower than in the reference scenario for the ten subsequent years following the acceleration (where a sharp drop in expenditure for refurbishment activities occurs). This can be explained (for financing option 1) by increased household expenditure in non-energy related sectors which show considerable higher value added multipliers than the energy sectors in Germany (see Section 7.4).

Compared to the reference scenario, the changes in total value added are small. However, individual sectors of the economy can be heavily affected in some policy scenarios and for some financing options (see Section 9.3 for details). The range of the value added effects is from 0.00 % to 0.23 % for all the years between 2000 and 2060 in Germany for financing option 1 (Table 39). The highest value added effects occur for the accelerated scenarios while, on average, the Full Coop scenario, followed by the Coop RR&WR scenario, leads to the best results without any abrupt changes in the economy.

In Poland, value added impacts are similarly small for financing option 1 with a range from -0.03 % to 0.10 % for the years 2000 to 2060. For the accelerated scenarios, negative impacts occur. This can easily be explained by lower VA multipliers in the construction sectors in Poland than for other GFCF sectors (see Section 7.4). In the first years of the accelerated scenarios, a significant shift to construction-related investment takes place which leads to decrease in VA. In subsequent years, this is offset by energy savings (VA multipliers for energy sectors are lower than non-energy related sectors).

For Spain, again, value added impacts are small for financing option 1. The effects range from 0.00 % to 0.18 % for the years 2000 to 2060. Like in Germany, the value added effects are positive for all scenarios in all years. The value added multiplier effects are similar to Germany in this case (see Section 7.4).

Table 39 Range of value added changes in % from 2000 to 2060 compared to reference (financing option 1)

	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR
Germany							
Maximum	0.06	0.18	0.06	0.06	0.10	0.11	0.23
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.05	0.07	0.05	0.05	0.05	0.06	0.07
Poland							
Maximum	0.08	0.10	0.08	0.08	0.08	0.08	0.09
Minimum	0.00	-0.03	0.00	0.00	-0.02	-0.02	-0.03
Average	0.07	0.07	0.06	0.06	0.06	0.06	0.06
Spain							
Maximum	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.15	0.14	0.16	0.13	0.14	0.13	0.14

When we look at the different financing options, we see that financing option 1 leads to best results for all policy scenarios on average in Germany (Figure 36). In addition, value added is always positive for all scenarios and all years. The financing options 3 and 4 also show positive results but negative impacts can occur for the accelerated scenarios in some years.

Financing option 5 leads to high negative impacts on value added. For this financing option, it is assumed that the government finances the additional renovation and refurbishment costs. The total government budget thus is decreased. The value-added multipliers for the construction-related industry sectors are by far lower than the VA multipliers for the average government expenditure in all countries (see Section 7.4).

The accelerated scenarios show the highest variation in results between the single years. For all financing options except for option 1, the impacts are negative in some years and positive in other years. This means, that adjustment problems in the economy can occur and heavy impacts on single sectors can be expected (see Section 9.3).

The value added impacts depend more on the policy scenario than on the single year for the non-accelerated scenarios. In the accelerated scenarios, the differences between single years are more pronounced than the differences between the single financing options.

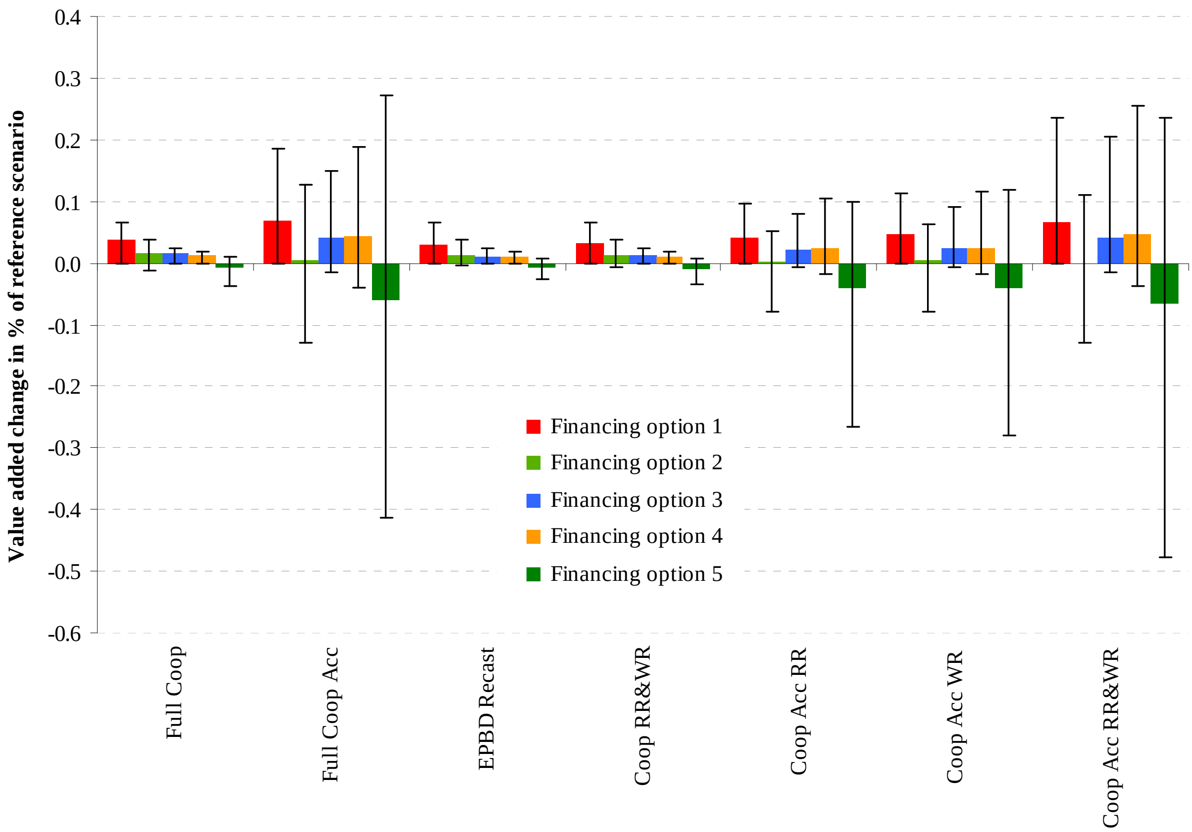

Figure 36 **Average value added impacts according to policy scenario for all financing options from 2000 to 2060 in Germany**
The error bars display the range of the effects for all the single years

In Poland, the results are comparable to Germany (Figure 37). On average, financing option 1 shows the best results. However, negative impacts can occur also for this option (see Table 39). Financing option 4 – governments financing the additional refurbishment and renovation activities – yields positive results for all scenarios on average, however, negative VA effects can occur for some years. Financing option 3 (energy costs savings are transferred to additional investment in non-construction related sectors) shows smallest impacts and also smallest variation between the years.

Again, the accelerated scenarios show a high variation of impacts depending on the individual year. Especially financing option 5 shows a big bandwidth of impacts. Again, adjustment problems can be expected for single sectors of the economy.

In Poland, the impacts on value added are positive for all policy scenarios and all financing options except for option 5 from 2045 on. For financing option 1, impacts are positive from 2023 on and for financing option 5, impacts are negative from 2033 for all scenarios.

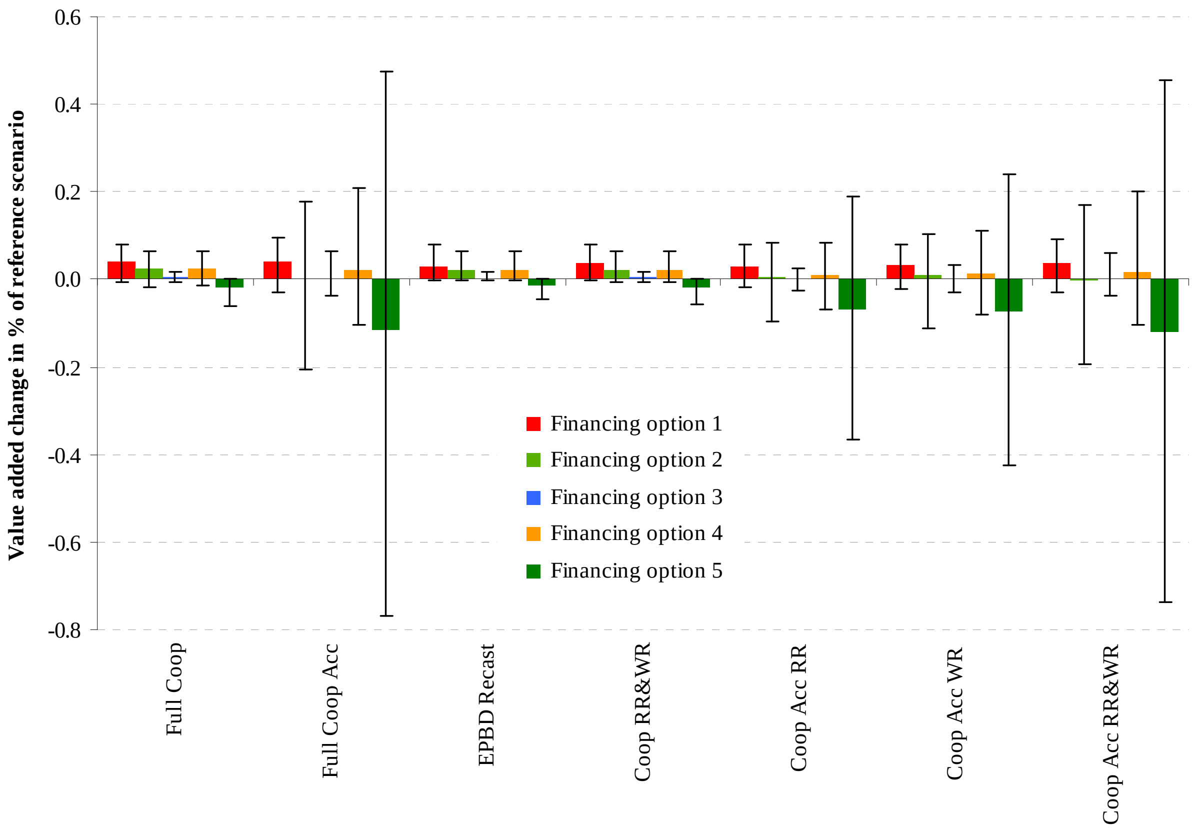

Figure 37 Average value added impacts according to policy scenario for all financing options from 2000 to 2060 in Poland
The error bars display the range of the effects for all the single years

The value added effects in Spain show on average positive values for all financing options and scenarios (Figure 38). This is very much due to the fact that the value added multiplier for energy-related expenses from households is significantly lower than for all other final demand categories (see Section 7.4). Energy cost savings thus lead to high positive value added effects which offset all counteracting effects.

Negative impacts occur only in the first years the policy scenarios apply. From about 2035, all impacts are positive in all scenarios and financing options. This break-even point is reached earlier in financing option 2 and option 3. For financing option 1, only positive impacts occur in all years.

The variation of the results is much higher in Spain compared to Poland and Germany and high variation occurs not only in the accelerated scenarios but also in the non-accelerated scenarios. The variation of results is much higher between single years than between the policy scenarios.

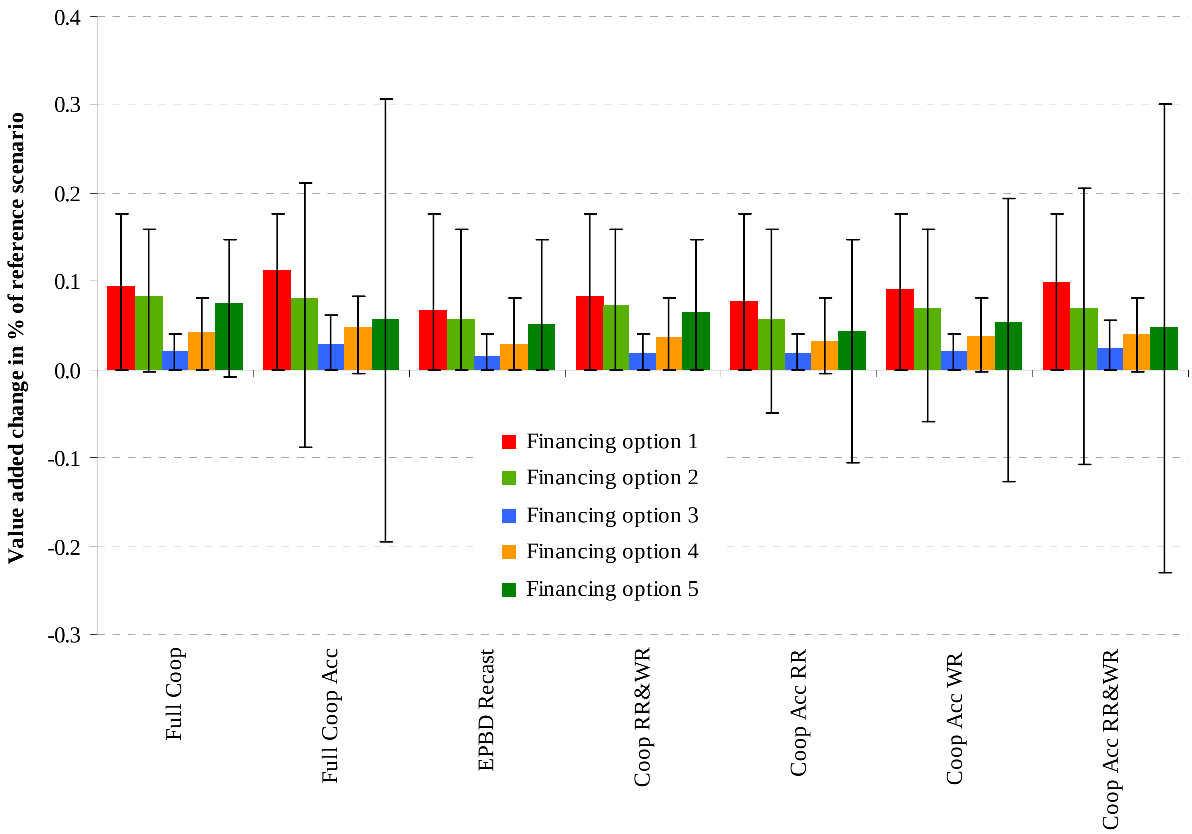

Figure 38 Average value added impacts according to policy scenario for all financing options from 2000 to 2060 in Spain
The error bars display the range of the effects for all the single years

9.2.2 Employment

The results for the calculation of the employment effects are similar to the results of the value added effects due to the similarities of the input-output multipliers (see Section 7.4).

Figure 39 displays the results of the input-output model calculations for the employment effects compared to the reference scenario as an example for financing option 1 and Germany. The employment effects show a similar pattern than the value added effects (Figure 35). However, for the accelerated scenarios, the employment effects can be negative in some years.

Again, there is a great impact of the accelerated scenarios during the acceleration periods (2009 to 2018 for the Full Coop Acc scenario, and 2014 to 2023 for the other accelerated scenarios). Increased investment in construction-related sectors leads to a sharp increase in employment in these periods. Employment can be lower than in the reference scenario for the ten subsequent years following the acceleration (where a sharp drop in expenditure for refurbishment activities occurs).

Concerning the non-accelerated scenarios, the Full Coop scenario scores best, followed by the Coop RR&WR scenario. The EPBD recast scenario is the worst of these more balanced scenarios.

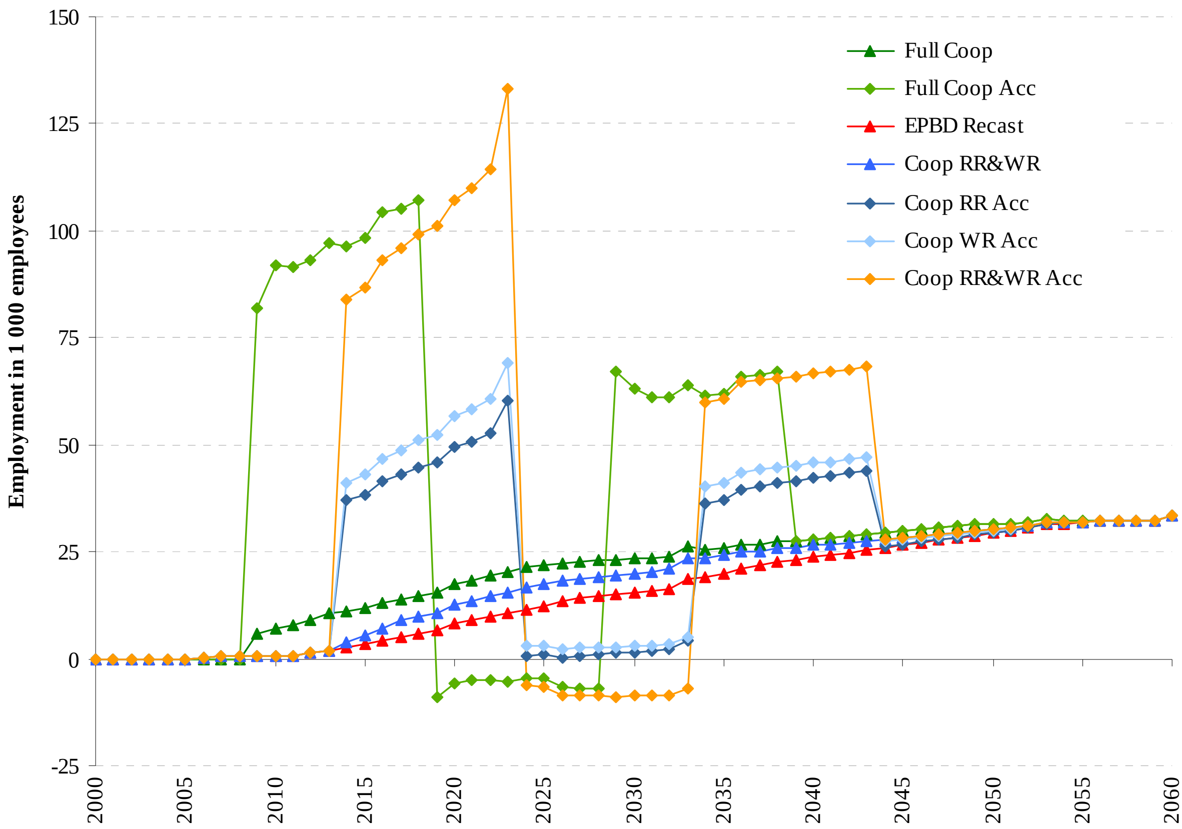

Figure 39 **Employment according to policy scenario from 2000 to 2060 compared to the reference scenario for Germany (financing option 1)**

The employment effects of the policy scenarios are small on average with respect to the whole economy. Individual sectors might be heavily affected in some policy scenarios and for some financing options (this is discussed more in detail in Section 9.3).

The employment effects range from -0.03 % to 0.38 % for all the years between 2000 and 2060 in Germany for financing option 1 (Table 40). On average, the Full Coop Acc and Coop Acc RR&WR scenarios show highest employment compared to the reference scenario. The accelerated scenarios score better than the non-accelerated scenarios on average.

In Poland, the employment impacts are even smaller for financing option 1. The impacts lie between 0.00 % to 0.08 % for the years 2000 to 2060. In addition, there do not occur any negative impacts like it is the case for value added in Germany (see Figure 35).

For Spain, again, value added impacts are more pronounced than in the other countries (concerning financing option 1). Here, the effects range from 0.00 % to 0.30 % for the years 2000 to 2060. As it is the case in Poland, no negative employment effects occur.

Table 40 Range of employment changes in % from 2000 to 2060 compared to reference (financing option 1)

	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR
Germany							
Maximum	0.09	0.30	0.09	0.09	0.17	0.20	0.38
Minimum	0.00	-0.03	0.00	0.00	0.00	0.00	-0.02
Average	0.08	0.10	0.07	0.07	0.08	0.08	0.10
Poland							
Maximum	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Spain							
Maximum	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.23	0.24	0.22	0.23	0.23	0.24	0.24

The differences between the single financing options are the same already observed for value-added impacts (see Section 9.2.1). The variation between the years tends to be a bit larger for employment compare to the valued-added impacts. In the following, we display the results for Germany only as an example. The conclusions concerning Spain and Poland remain the same than for value added.

Financing option 1 on average leads to better impacts on employment than the other financing options except for the EE Boundary Low scenario (Figure 40). However, negative employment effects can also occur in some accelerated scenarios for this financing option. The financing options 3 and 4 also show positive results on average, but again, negative impacts can occur for the accelerated scenarios in some years. Financing option 2 leads to ambiguous results, too with negative impacts possible and a high range of variation between the years. Financing option 5 leads to negative impacts on employment on average with high variation.

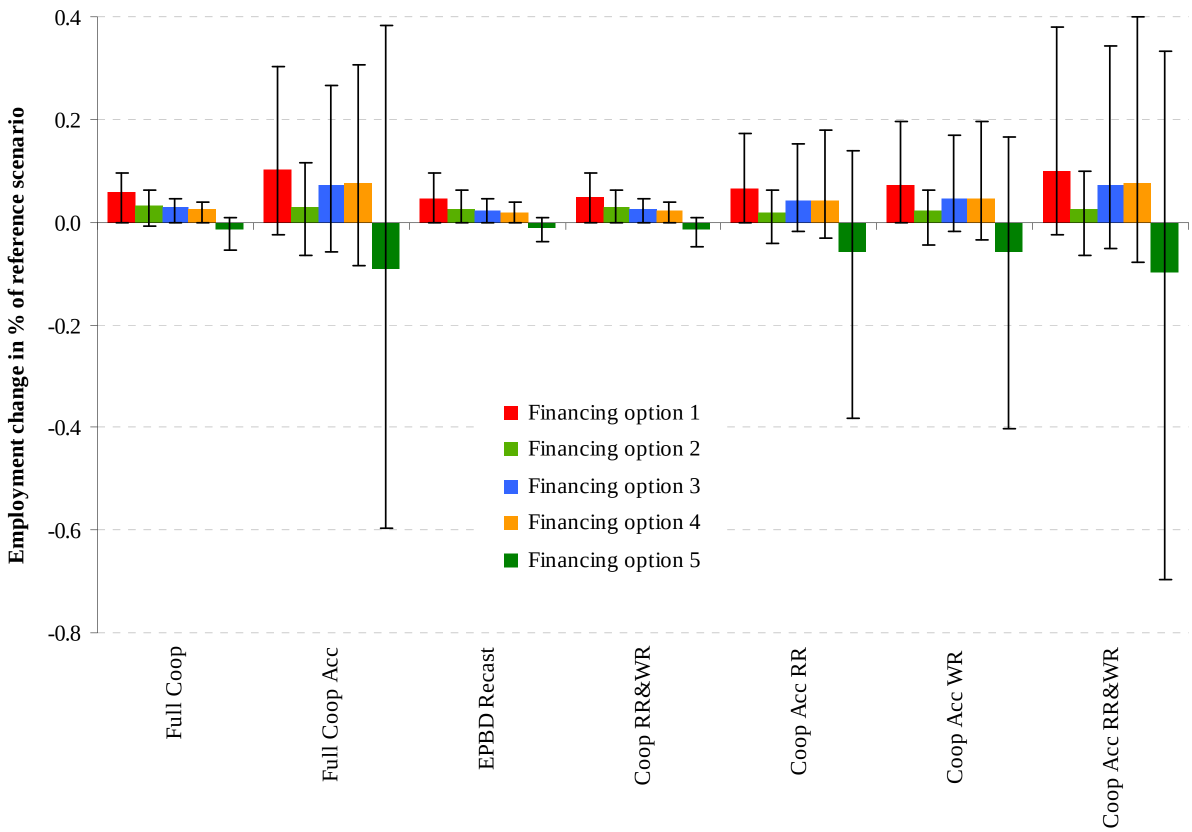

Figure 40 **Average employment impacts according to policy scenario for all financing options from 2000 to 2060 in Germany**
The error bars display the range of the effects for all the single years

Like for value added, the accelerated scenarios show the highest variation in results between the single years. For all financing options, the impacts are negative in some years and positive in other years in these scenarios. This means, that adjustment problems in the economy can occur and heavy impacts on single sectors can be expected (see Section 9.3).

The employment impacts depend more on the policy scenario than on the single year for the non-accelerated scenarios. In the accelerated scenarios, the differences between single years are more pronounced than the differences between the single financing options.

9.2.3 Compensation of employees

The results for compensation of employees follow closely the results for value-added and employment. The changes of the compensation of employees resulting compared to the reference scenario for financing option 1 and Germany are shown in Figure 41. For financing option 1, the effects on the compensation of employees are always positive (like the value-added impacts).

The accelerated scenarios show the same pattern during the acceleration periods. Increased investment in construction-related sectors leads to a sharp increase in compensation of employees in these periods. Compensation of employees is never lower than in the reference scenario for the ten subsequent years following the acceleration (where a sharp drop in expenditure for refurbishment activities occurs).

Like for employment and value added, the Full Coop scenario scores best, concerning the non-accelerated scenarios. The Coop RR&WR scenario scores second best while the EPBD recast scenario is the worst of these more balanced scenarios.

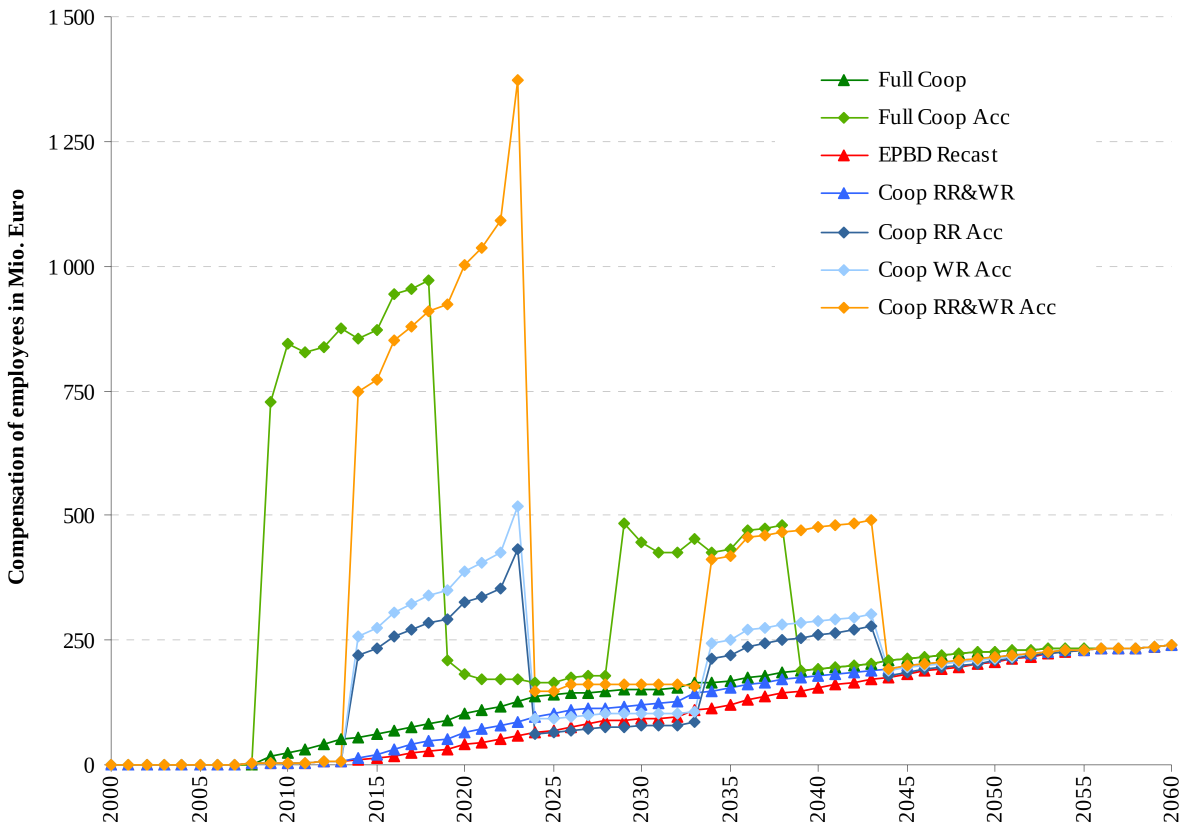

Figure 41 **Compensation of employees according to policy scenario from 2000 to 2060 compared to the reference scenario for Germany (financing option 1)**

Compared to the total compensation of employees, the scenario impacts are small (Table 41). However, the compensation of employees of some individual sectors might be heavily affected in specific scenarios and for some financing options (see Section 9.3).

In all three countries, the scenarios do not lead to negative effects on compensation of employees. The employment effects can reach up to 0.12 % for all the years between 2000 and 2060 in Germany, up to 0.09 % in Poland and up to 0.17 % in Spain.

The ranking of the scenarios is the same than for value added and employment. Concerning the non-accelerated results, on average, the Full Coop scenario leads to the best results, followed by the Coop RR&WR and the EPBD recast scenario. On average, the accelerated scenarios score better than the non-accelerated scenarios.

Table 41 Range of compensation of employees changes in % from 2000 to 2060 compared to reference (financing option 1)

	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR
Germany							
Maximum	0.02	0.09	0.02	0.02	0.04	0.05	0.12
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Poland							
Maximum	0.04	0.09	0.04	0.04	0.04	0.05	0.09
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.03	0.04	0.03	0.03	0.03	0.04	0.04
Spain							
Maximum	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.14	0.15	0.12	0.13	0.13	0.13	0.14

The differences between the single financing options follow the observations for the impacts on value added and employment (see Section 9.2.1 and Section 9.2.2). The results for compensation of employees are thus not displayed here because also the conclusions with regards to the ranking and valuation of the financing options remain valid.

9.2.4 Greenhouse gas emissions

The greenhouse gas emissions by the whole economy (without the emissions from households) were calculated by the input-output-model. We added the emissions from households for space heating (see Section 9.1.6) in order to calculate the total change in emissions due to the policy scenarios.

The greenhouse gas emissions can be reduced by all policy scenarios for financing option 1 in Germany (Figure 42). All scenarios converge in 2055 to annual savings of about 34 Mt CO_2-equivalents. The best results are achieved with the Full Coop scenarios, followed by the Coop scenarios. Not surprisingly, the EPBD recast scenario leads to smallest emission reductions compared to the reference scenario. The results are driven by the emissions from households and not by industry emissions (compare Figure 29).

There are only small effects in the first (or the first two) years of the acceleration scenarios where total emissions can increase due to increased construction activity and thus emissions which are not offset by GHG savings due to energy savings. In addition, clearly, the effects of the decrease of refurbishment activity during the 10 years following the acceleration scheme can be seen: greenhouse gas emissions show a drop in these years which is more pronounced for the Full Coop Acc and the Coop RR&WR Acc scenarios compared to the scenarios with accelerated refurbishment of only one building element (either roofs or windows).

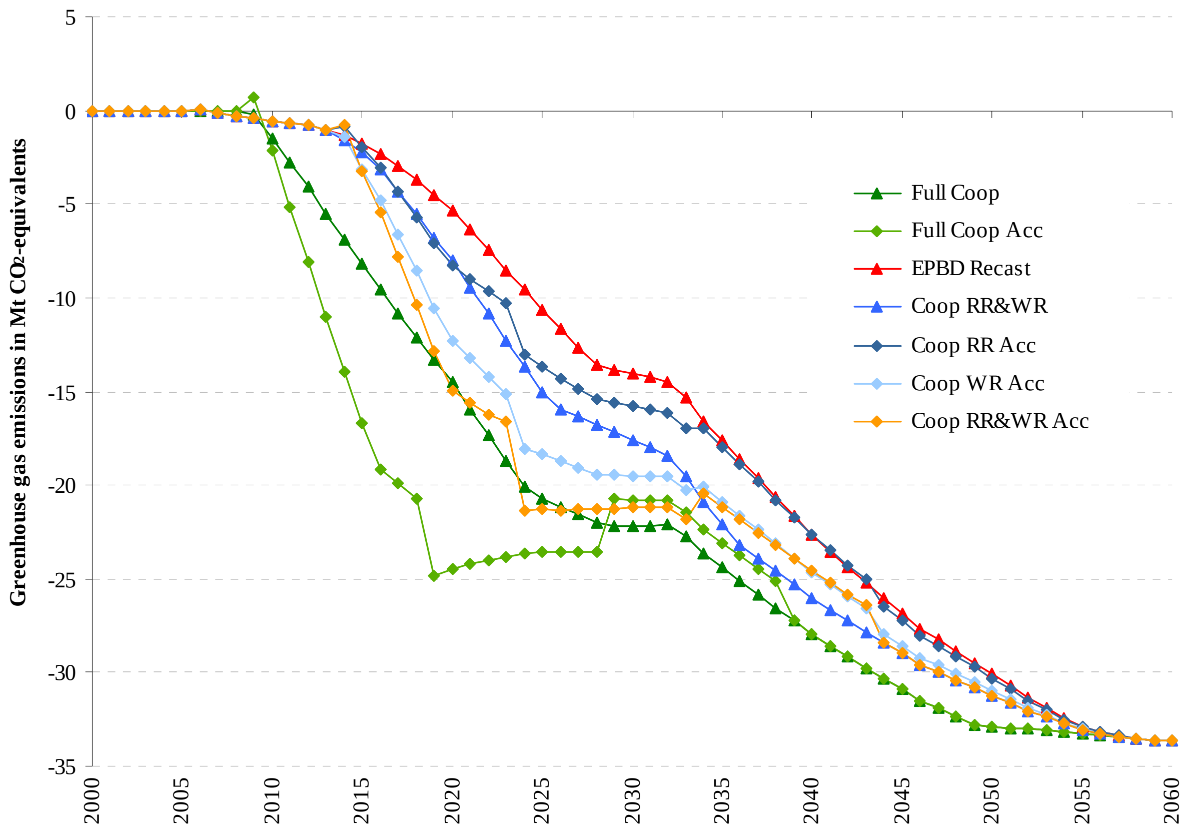

Figure 42 **GHG emissions according to policy scenario from 2000 to 2060 compared to the reference scenario for Germany (financing option 1)**

The results for Poland and Spain can be compared with the results for Germany. In general, the ranking of the policy scenarios with respect to GHG emission savings remains the same with some minor exceptions driven by the emissions from household space heating (see Section 9.1.6).

The relative greenhouse gas emissions (industry and household emissions) compared to the reference scenario for financing option 1 are summarised in Table 42. On average, the GHG emissions savings correspond to 2.7 % to 3.1 % in Germany, to 4.6 % to 5.1 % in Poland and to 1.3 % to 1.6 % in Spain. The greatest reductions are achieved by the Full Coop Acc scenarios, followed by the Full Coop scenario and the Coop Acc RR&WR scenario in all countries.

Table 42 Range of GHG emission changes in % from 2000 to 2060 compared to reference (financing option 1)

	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR
Germany							
Maximum	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Minimum	-3.91	-3.91	-3.91	-3.91	-3.91	-3.91	-3.91
Average	-2.99	-3.10	-2.68	-2.81	-2.73	-2.85	-2.89
Poland							
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	-6.14	-6.14	-6.14	-6.14	-6.14	-6.14	-6.14
Average	-4.96	-5.14	-4.56	-4.75	-4.63	-4.81	-4.89
Spain							
Maximum	0.00	0.06	0.00	0.00	0.02	0.00	0.04
Minimum	-1.86	-1.86	-1.86	-1.86	-1.86	-1.86	-1.86
Average	-1.51	-1.58	-1.33	-1.44	-1.37	-1.46	-1.49

The absolute cumulative greenhouse gas emission savings are highest for Germany, followed by Spain and Poland (Table 43). As mentioned before, the highest savings can be achieved by the Full Coop Acc, followed by the Full Coop and Coop RR&WR scenarios.

Table 43 Cumulative GHG emission savings from 2000 to 2060 compared to reference (financing option 1)

Country	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR
				Mt CO_2-equivalents			
Germany	1 182	1 277	913	1 023	954	1 056	1 095
Poland	297	324	238	266	250	275	287
Spain	362	402	256	322	281	332	351
				Mt CO_2-equivalents per year			
Germany	19.4	20.9	15.0	16.8	15.6	17.3	17.9
Poland	4.9	5.3	3.9	4.4	4.1	4.5	4.7
Spain	5.9	6.6	4.2	5.3	4.6	5.4	5.8

When we look at the different financing options, the GHG emission reductions do not differ much in Germany (Figure 43). This is also true for the other countries, thus, they are not displayed here. The GHG emission savings variation is greater over the years (bandwidth in Figure 43) than for financing options. This can be explained by the fact, that the emission savings are vastly driven by the savings from household not by industry-related emissions (which are affected by the financing option only). Thus, for greenhouse gas emissions, the financing option and thus the policy instrument does not play a major role, however, the policy instrument chosen does make a difference for the socio-economic impacts.

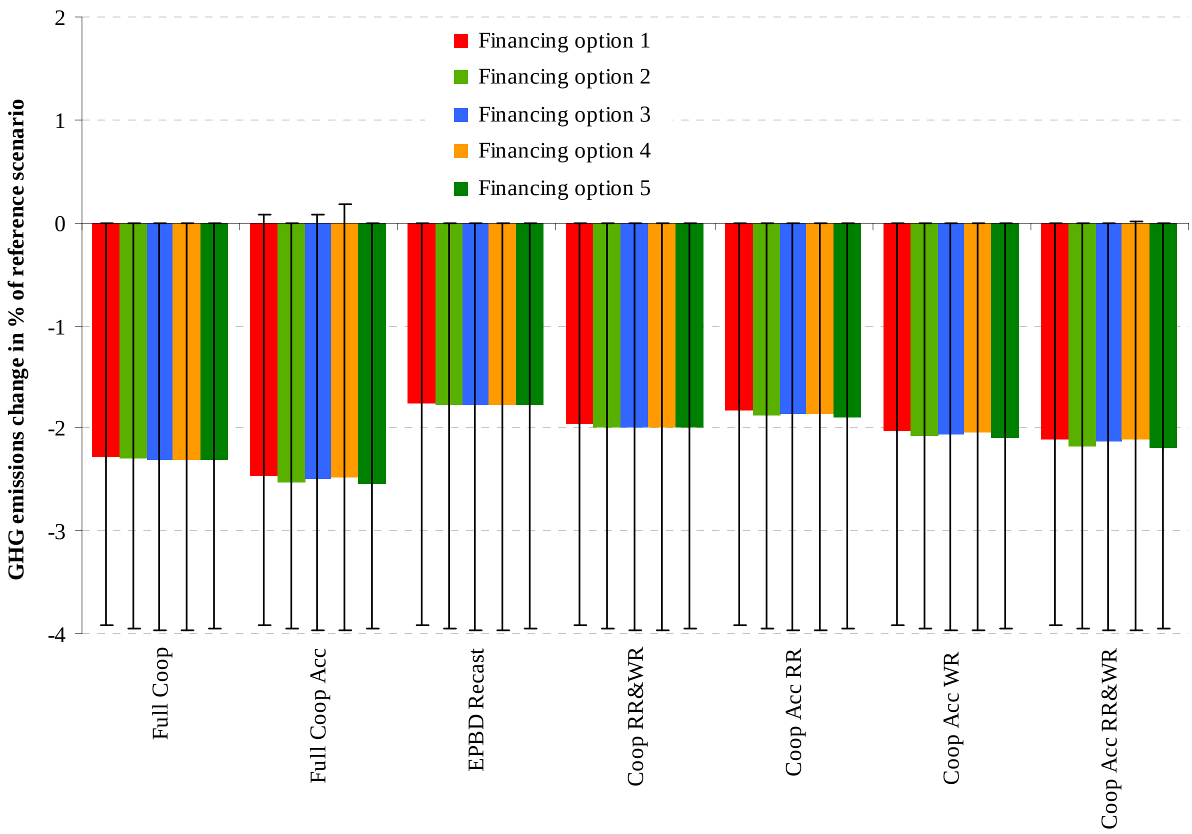

Figure 43 Average greenhouse gas emission impacts according to policy scenario for all financing options from 2000 to 2060 in Germany
The error bars display the range of the effects for all the single years

9.2.5 Welfare

The welfare effect of the policy scenarios was calculated according to the methodology described in Section 7.1. The welfare effect measures the net costs of a policy to the whole society with positive welfare effects representing negative net costs. The results are similar to the net costs for households (see Section 9.1.8) but include also indirect and rebound effects.

In Figure 44, the welfare effects of the policy scenarios are displayed for financing option 1 and Germany as an example. For the non-accelerated scenarios (Full Coop, EPBD Recast, Coop RR&WR), welfare is decreased compared to the reference scenario due to higher spending for renovation and refurbishment measures which outweigh the energy cost savings. In course of time, the welfare increases due to increases in energy cost savings. The investments thus pay back and break even will be reached in the 2030s. The policy measures thus pay off soon (after about 20 years).

For the accelerated scenarios, the picture is different. During the accelerated phases, a substantial decrease of welfare takes place which is only in part being offset after the acceleration. The economy will be significantly affected by these scenarios, especially when a policy is just being introduced or about to end. Again, there will be economy sectors that will be winners and sectors that will be losers according to the specific policy scenario (see Section 9.3).

For Poland and Spain, the results are the same than for Germany (for financing option 1). However, in the non-accelerated scenarios, a positive welfare effect will be reached sooner than in Germany (between 2010-2015 in Spain and between 2016 and 2022 in Poland). For the accelerated scenarios, the conclusions are the same than for Germany (compare also the results on net costs in Section 9.1.8).

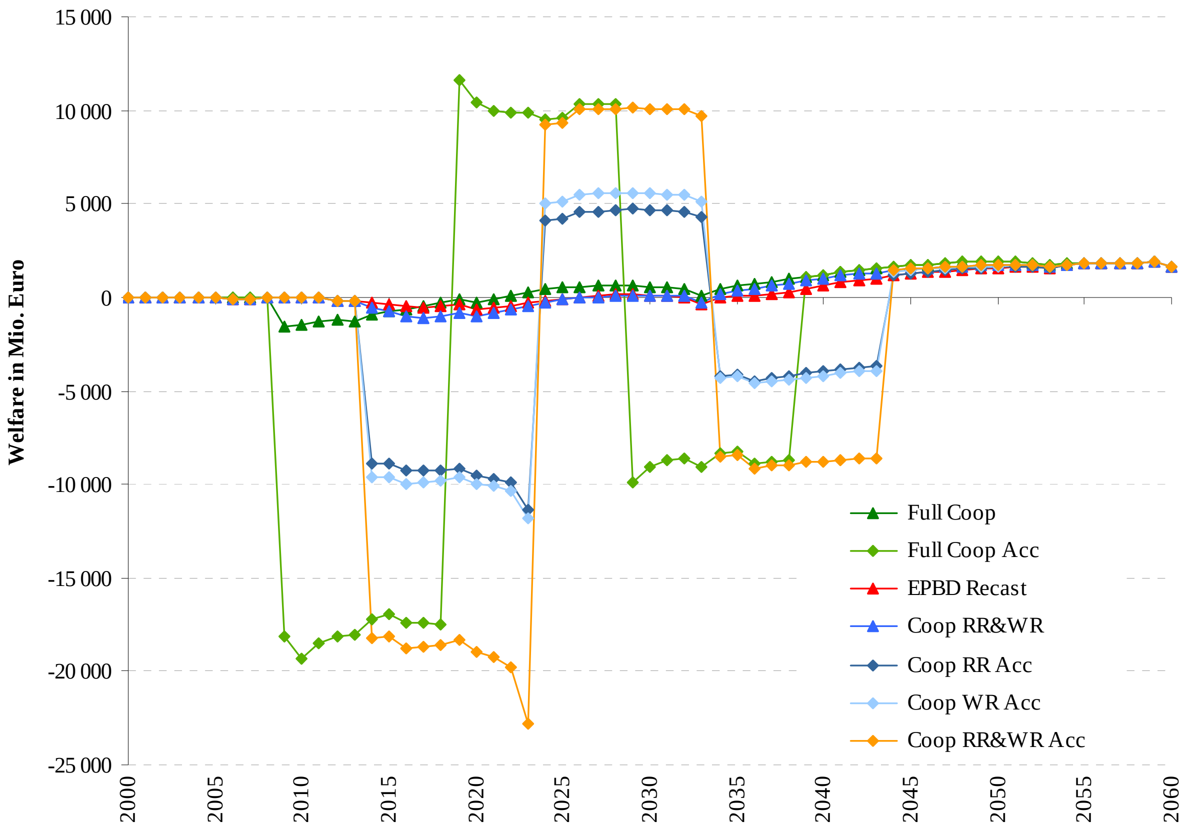

Figure 44 Welfare changes according to policy scenario from 2000 to 2060 compared to the reference scenario for Germany (financing option 1)

The relative impacts on the welfare of the whole society are quite small for financing option 1 (Table 44). In Germany, welfare effects range from -1.4 % to 0.7 % including all scenarios and all years. In Poland, the effects range from -0.8 % to 0.7 % while in Spain, impacts are smaller (-0.3 % to 0.4 %). In Germany, on average, all accelerated policy scenarios lead to a loss in welfare. This is due to small positive welfare effects which do not offset the negative impacts in the years of accelerated refurbishment (see Figure 44). On contrary, for Poland and Spain, on average, all scenarios lead to positive welfare effects.

Table 44 Range of welfare changes in % from 2000 to 2060 compared to reference (financing option 1)

	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR
Germany							
Maximum	0.12	0.72	0.12	0.12	0.29	0.35	0.63
Minimum	-0.10	-1.19	-0.04	-0.07	-0.70	-0.73	-1.41
Average	0.02	-0.15	0.01	0.01	-0.08	-0.08	-0.17
Poland							
Maximum	0.29	0.67	0.29	0.29	0.34	0.42	0.64
Minimum	-0.06	-0.79	-0.01	-0.01	-0.34	-0.40	-0.75
Average	0.13	0.03	0.10	0.12	0.05	0.05	0.00
Spain							
Maximum	0.32	0.44	0.32	0.32	0.32	0.32	0.43
Minimum	-0.01	-0.20	0.00	0.00	-0.11	-0.13	-0.25
Average	0.12	0.11	0.09	0.11	0.08	0.10	0.09

In all countries, the best scenario concerning welfare clearly is the Full Coop scenario. The next best scenario is the Coop RR&WR for Spain in Poland. In Germany, also the EPBD recast scenario leads to good results concerning welfare.

Regarding the results for all financing options, we see that the variation between the single financing options is very small compared to the variation over the years for the accelerated scenarios (Figure 45). The selection of the financing option thus does not create any major differences in welfare; instead, it is the choice of the policy scenario that makes the difference.

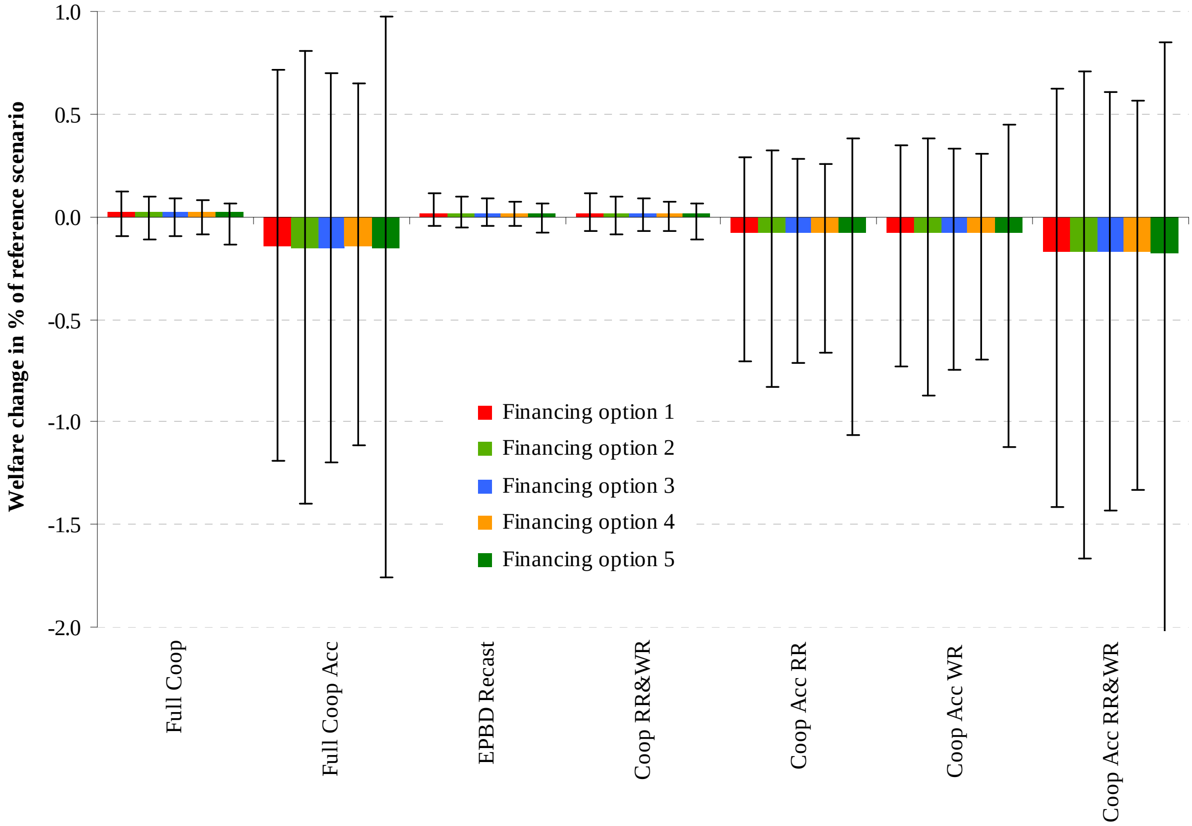

Figure 45 Average welfare impacts according to policy scenario for all financing options from 2000 to 2060 in Germany
The error bars display the range of the effects for all the single years

For Poland and Spain, the results are similar to the results for Germany. Again, the differences between the individual financing options are very small compared to the variation over the years. However, in Poland and Spain, the bandwidth of the results according to the years is more comparable for the non-accelerated scenarios and smaller for the accelerated scenarios.

9.3 Detailed results for the individual policy scenarios

For the policy scenarios (not the theoretical ‘what-if’ scenarios), we will analyse the impacts more in detail. We will especially focus on the implications of the policies for individual sectors of the economy and we will analyse which financing option leads to the best results and might be best suited to the policy measures or instruments to apply.

9.3.1 EPBD recast scenario

The results for the EPBD recast scenario are summarised in Table 45 as the average results from 2000 to 2060 for the different financing options (see Section 7.3). When we compare the different options, we see that in terms of impacts on economy and society the option 1 (constant household and GFCF budget) yields the best results. The option 5 (government financing of additional renovation and refurbishment scores worst; it leads to losses in value added, employment and tax revenue and net welfare is reduced dramatically. Due to this impact on the economy, the greenhouse gas emissions are lower for this option than for the other options (the general decrease of economic activity leads to a reduction of emissions). However, the relative differences for GHG emission reductions are quite small compared to the range of results for the other (socio-economic) parameters.

Table 45 Results for the EPBD recast scenario compared to reference scenario (average from 2000 to 2060)

Country	Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5
Germany	Value added	Mio. Euro/a	537.6	228.7	204.2	165.2	-121.7
	Employment	1 000 Employees/a	15.7	8.7	8.0	7.2	-3.9
	Compensation of employees	Mio. Euro/a	103.1	78.6	89.8	61.3	-390.1
	GHG reductions	Mt CO_2-eq. /a	15.0	15.1	15.2	15.2	15.2
	Tax revenue	Mio. Euro/a	116.8	19.4	6.9	-2.233	106.9
	Welfare	Mio. Euro/a	430.7	226.2	224.7	173.4	-143.4
Spain	Value added	Mio. Euro/a	265.3	230.3	58.3	115.9	204.3
	Employment	1 000 Employees/a	50.2	44.9	18.2	19.4	42.6
	Compensation of employees	Mio. Euro/a	128.4	111.6	28.8	66.3	80.7
	GHG reductions	Mt CO_2-eq. /a	4.2	4.3	4.7	4.6	4.3
	Tax revenue	Mio. Euro/a	40.3	24.6	-55.2	-51.3	32.8
	Welfare	Mio. Euro/a	637.9	601.1	424.2	457.1	578.4
Poland	Value added	Mio. Euro/a	30.4	20.1	3.2	19.3	-14.9
	Employment	1 000 Employees/a	2.1	1.6	0.9	2.4	-2.7
	Compensation of employees	Mio. Euro/a	7.6	3.0	-4.5	5.7	-32.2
	GHG reductions	Mt CO_2-eq. /a	3.9	3.9	4.0	4.0	3.9
	Tax revenue	Mio. Euro/a	4.1	-3.9	-18.6	-17.9	0.0
	Welfare	Mio. Euro/a	163.1	144.7	114.1	122.0	114.3

For financing options 1, 3 and 4, the results are always positive results for value added, employment, and compensation of employees in all years between 2000 and 2006. Tax revenue and welfare impacts range from negative to positive values. For the financing options 2 and 5, the results range from negative to positive values for all parameters (Figure 46). The greenhouse gas emissions saving do not differ significantly between the financing options.

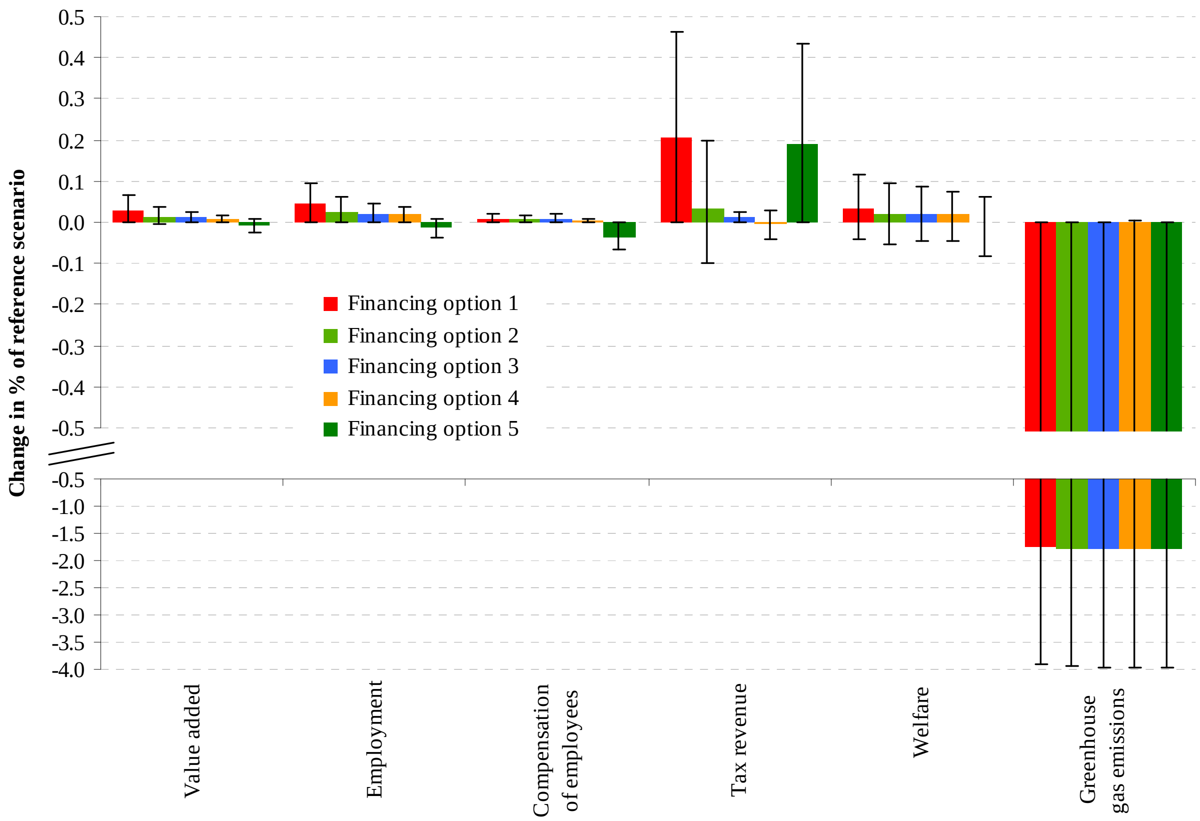

Figure 46 **Average changes of the EPBD recast scenario compared to the reference scenario from 2000 to 2060 in Germany**
The error bars display the range of the effects for all the single years

In general, the impacts on sectoral output are small for the EPBD recast scenario. The maximum changes in output range from -5.2 % to 1.2 % for financing option 1, all sectors and the years 2000 to 2060 in Germany.

For the ten most affected sectors, the impacts on sectoral output is shown for the years 2015, 2025, and 2050 for financing option 1 in Germany (Figure 47).[22] The majority of the most affected sectors that show a reduction (e.g. ‘coal and lignite & peat’ and ‘electrical energy, gas, steam and hot water’) are energy-related sectors with the decrease of output due to energy savings in private households.

Some sector show an increase in output which is caused by increased expenditure for renovation and refurbishment and because it was assumed that the consumers spend the money they saved for energy on other consumption items (see Section 7.3). It is remarkable, that the relative change in most of these sectors is higher than the increases in the construction sector itself (increase in output of 0.2 %, 0.4 %, and 0.6 %, respectively for the years 2015, 2025, and 2050). From 2015 to 2050 the energy savings increase which is reflected in increasing impacts on the energy-related sectors.

[22] These years are chosen in order to show the differences in the accelerated scenarios for periods where the refurbishment is accelerated and periods without acceleration.

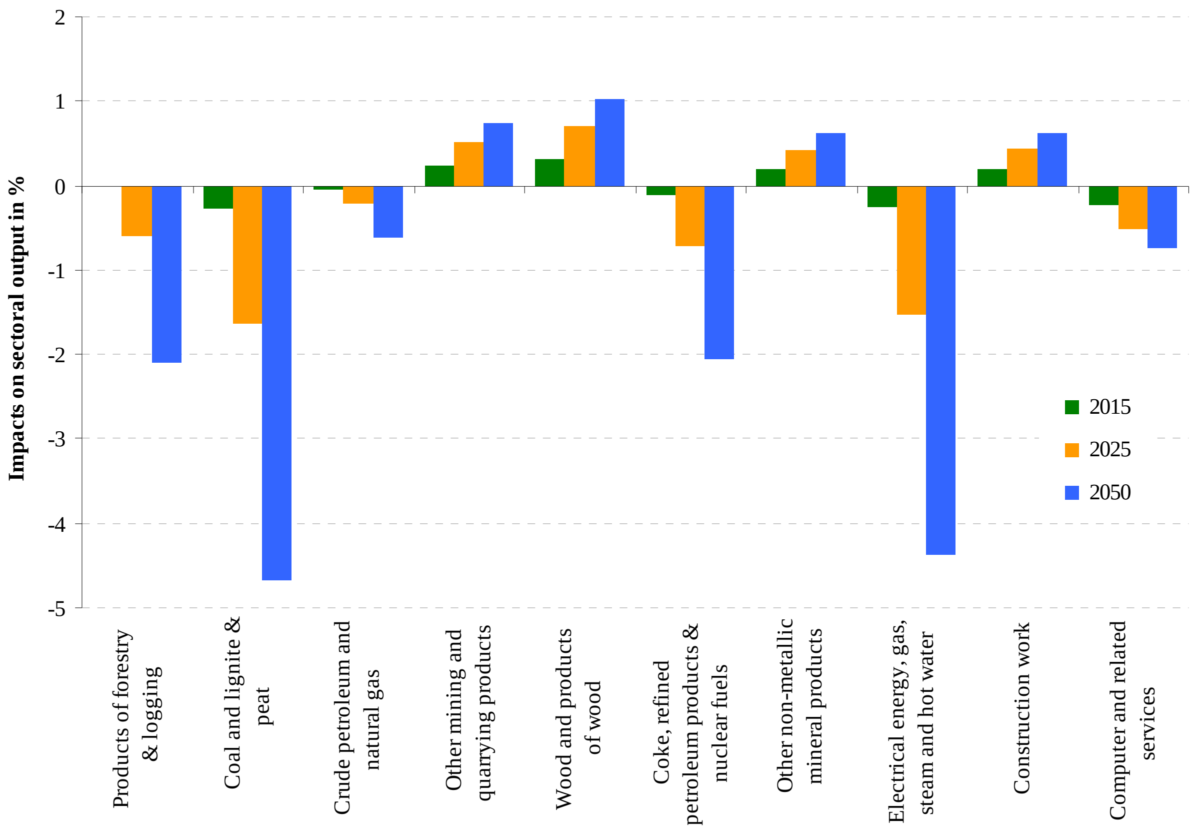

Figure 47 Impacts on sectoral output for the EPBD recast scenario compared to the reference scenario for Germany (financing option 1)

To summarise the analysis of the EPBD recast scenario, the advantages and disadvantages of the scenario are displayed in Table 46. The main advantage of the EPBD recast scenario is that there is no need for an additional policy instrument. Concerning the socioeconomic and environmental indicators, the scenario does not score very well compared to the other policy scenarios.

Table 46 Summary of the EPBD recast scenario analysis

Socioeconomic impacts	
+	No abrupt changes/shocks in economy
+/–	Intermediate welfare results compared to other scenarios
–	Lowest GHG emission reductions of all scenarios
–	Low value added scores compared to other scenarios
–	Low employment scores compared to other scenarios
–	Low compensation of employees scores compared to other scenarios
–	Low tax revenue scores compared to other scenarios
Policy instruments/measures	
Existing instruments including the EPBD recast Commission proposal. No need for a new policy instrument	
Financing options	
+	Financing option 1
+/–	Financing options 2-4
–	Financing option 5

9.3.2 Full cost optimal scenario

Table 47 shows the results for the full cost optimal scenario compared to the reference scenario. When we compare the different financing options, we see that in terms of socio-economic impacts, the financing option 1 yields the best results (see Section 7.3). As it is the case for the EPBD scenario (see Section 9.3.1), financing option 5 scores worst with respect to value added, employment, and compensation of employees, tax revenue, and welfare. Again, GHG emissions reductions are greatest for financing option 5 in this scenario with only small changes between the single options, however.

Table 47 Results for the Full Coop scenario compared to reference scenario (average from 2000 to 2060)

Country	Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5
Germany	Value added	Mio. Euro/a	697.8	305.3	265.1	213.2	-138.9
	Employment	1 000 Employees/a	20.3	11.4	10.2	9.3	-4.6
	Compensation of employees	Mio. Euro/a	135.5	104.2	118.2	79.2	-490.3
	GHG reductions	Mt CO_2-eq. /a	19.4	19.6	19.6	19.7	19.7
	Tax revenue	Mio. Euro/a	151.3	27.6	8.7	-3.799	138.7
	Welfare	Mio. Euro/a	593.9	334.3	326.6	257.6	-134.8
Spain	Value added	Mio. Euro/a	375.2	330.9	82.3	166.2	298.2
	Employment	1 000 Employees/a	70.8	64.1	25.6	27.3	61.3
	Compensation of employees	Mio. Euro/a	181.3	160.1	40.4	94.9	121.2
	GHG reductions	Mt CO_2-eq. /a	5.9	6.0	6.6	6.6	6.0
	Tax revenue	Mio. Euro/a	56.9	37.1	-78.3	-72.6	47.4
	Welfare	Mio. Euro/a	915.9	869.5	613.4	661.4	840.9
Poland	Value added	Mio. Euro/a	38.8	25.9	4.7	25.3	-17.4
	Employment	1 000 Employees/a	2.6	2.0	1.1	3.1	-3.3
	Compensation of employees	Mio. Euro/a	9.8	4.1	-5.3	7.6	-39.6
	GHG reductions	Mt CO_2-eq. /a	4.9	4.9	5.0	5.0	4.9
	Tax revenue	Mio. Euro/a	5.2	-4.8	-23.2	-22.4	0.1
	Welfare	Mio. Euro/a	205.4	182.5	144.0	154.0	144.8

In the Full Coop scenario, for financing options 1, the socio-economic impacts on value added, employment, compensation of employees, and tax revenue is positive in all years between 2000 and 2060 (Figure 48). The welfare effects include negative and positive values for these financing options.

With respect to the financing option 4, the effects on value added, employment, and compensation of employees is always positive while for tax revenue, also (small) negative impacts can occur. For financing options 2 and 5, negative and positive impacts can be seen for all parameters.

The greenhouse gas emissions saving do not differ significantly between the financing options with lowest savings for financing option 1 and highest savings for option 5. Overall, the impact pattern is quite similar to the EPBD recast scenario (see Section 9.3.1).

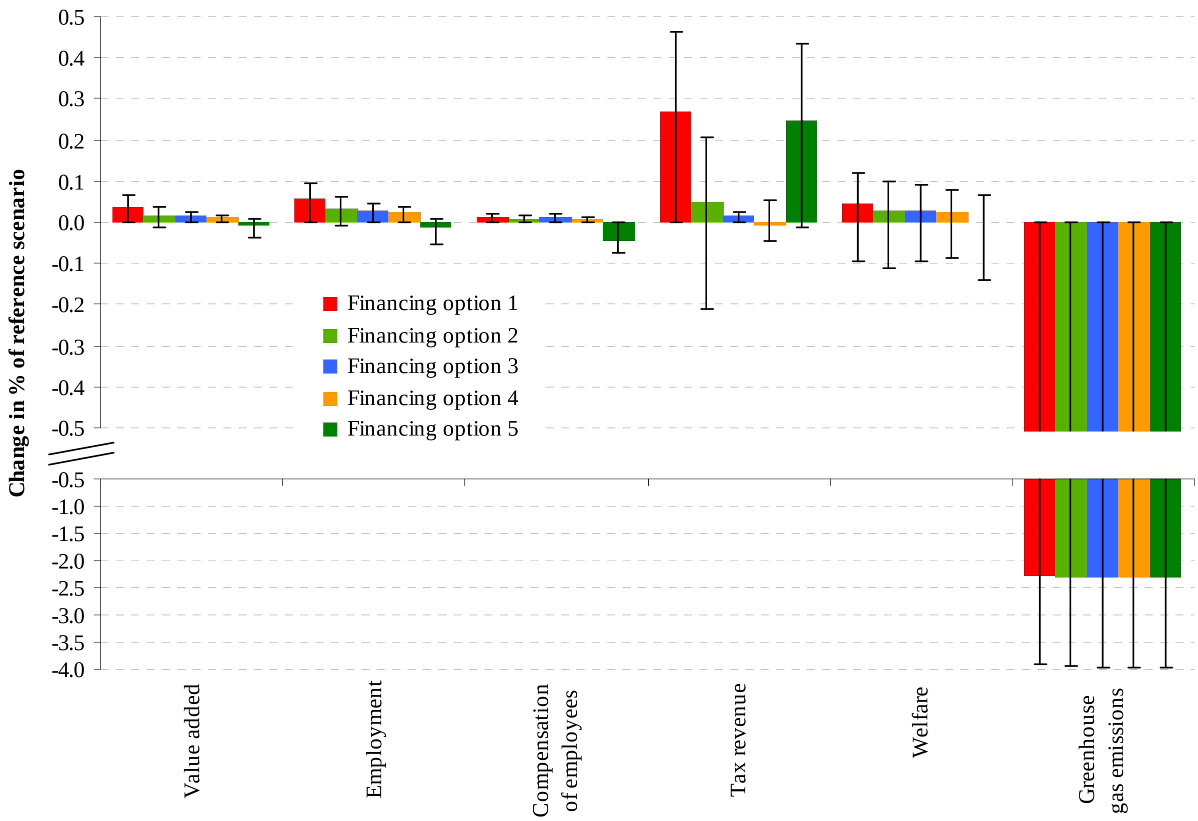

Figure 48 **Average changes of the Full Coop scenario compared to the reference scenario from 2000 to 2060 in Germany**
The error bars display the range of the effects for all the single years

The impacts on individual sectors of the economy are small in the Full Coop scenario as it is the case in the EPBD recast scenario. The maximum changes in sectoral output range from -5.2 % to 1.4 % for financing option 1, all sectors and the years 2000 to 2060 in Germany.

Figure 49 shows the impacts on sectoral output for the years 2015, 2025, and 2050 for financing option 1 in Germany as an example for the ten most affected sectors of the economy. The ten most affected sectors are the same than in the EPBD recast scenario. The majority of the most affected sectors that show a reduction are energy-related sectors. The decrease in these sectors is induced by energy savings in private households. For the other sectors, the decrease is due to a shift of investment to the construction-related sectors at the expense of investment (GFCF) in other sectors.

Increases in sectoral output can be stated for the construction-related sectors (e.g. mining and quarrying) due to increased expenditure for renovation and refurbishment and because of reallocation of household expenditure (energy cost savings are spent on other consumption items) in this financing option.

Again, from 2015 to 2050 the energy savings increase which is reflected in increasing impacts on the energy-related sectors. At the same time, also the expenditure for renovation and refurbishment increases and thus the impacts on the construction-related sectors show an increase.

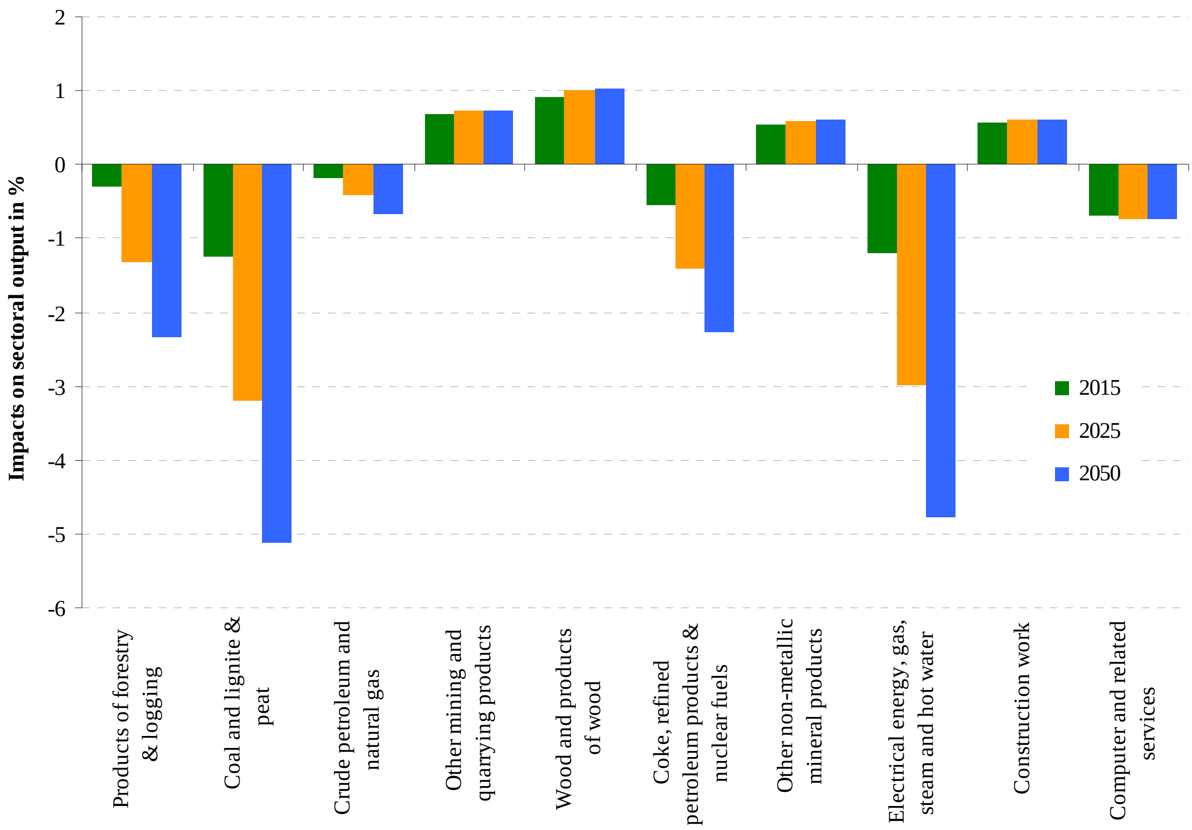

Figure 49 **Impacts on sectoral output for the Full Coop scenario compared to the reference scenario for Germany (financing option 1)**

A summary of the advantages and disadvantages of the Full Coop scenario is given in Table 48. The Full Coop scenario is one of the best scenarios with respect to greenhouse gas emissions and welfare. No very pronounced or abrupt shocks for individual sectors in the economy occur. Concerning value added, employment, and compensation of employees, the scenario performs very well compared to the other policy scenarios.

Table 48 **Summary of the Full Coop scenario analysis**

Socioeconomic impacts	
+	Second best scenario with respect to GHG emission reductions
+	No abrupt changes/shocks in economy
+	Best welfare results compared to other scenarios
+/–	Highest value added scores compared to other scenarios without acceleration
+/–	Highest employment scores compared to other scenarios without acceleration
+/–	Highest compensation of employment scores compared to other scenarios without acceleration
+/–	Intermediate tax revenue scores compared to other scenarios
Policy instruments/measures	
Additional/new policy instrument needed assuring that whenever renovation or refurbishment takes place, the cost optimal EE level is reached. These include minimum performance requirements for roofs and windows as well as exterior walls.	
Financing options	
+	Financing option 1
+/–	Financing options 3-4
–	Financing options 2 & 5

9.3.3 Full cost optimal accelerated scenario

The overall results for the full cost optimal accelerated scenario according to financing option are summarised in Table 49. Clearly, financing option 1 shows to be advantageous concerning all impacts except for the reduction of greenhouse gas emissions where, again, financing option 5 shows slightly better results (see Section 9.3.1).

In Spain, in general, financing option 2 is the second-best option except for tax revenue while for Germany and Poland, financing option 4 is the second-best option for most parameters.

Table 49 Results for the Full Coop Acc scenario compared to reference scenario (average from 2000 to 2060)

Country	Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5
Germany	Value added	Mio. Euro/a	1235.8	63.4	747.3	812.9	-1100.2
	Employment	1 000 Employees/a	36.5	10.6	25.2	26.6	-31.9
	Compensation of employees	Mio. Euro/a	325.2	197.5	299.9	418.0	-1396.7
	GHG reductions	Mt CO_2-eq. /a	20.9	21.6	21.2	21.1	21.8
	Tax revenue	Mio. Euro/a	176.6	-175.0	18.8	56.0	142.3
	Welfare	Mio. Euro/a	-2095.2	-2833.3	-2392.6	-2272.1	-4163.8
Spain	Value added	Mio. Euro/a	450.9	321.8	115.5	188.9	230.3
	Employment	1 000 Employees/a	84.9	65.4	33.1	34.2	57.5
	Compensation of employees	Mio. Euro/a	220.8	158.7	59.4	106.7	49.1
	GHG reductions	Mt CO_2-eq. /a	6.6	6.9	7.3	7.3	6.8
	Tax revenue	Mio. Euro/a	68.8	11.9	-85.5	-81.6	41.6
	Welfare	Mio. Euro/a	862.3	728.6	516.7	551.2	646.2
Poland	Value added	Mio. Euro/a	41.3	2.1	3.2	20.3	-113.1
	Employment	1 000 Employees/a	3.1	1.3	1.4	2.5	-13.1
	Compensation of employees	Mio. Euro/a	17.2	-0.4	0.2	8.0	-117.6
	GHG reductions	Mt CO_2-eq. /a	5.3	5.4	5.4	5.4	5.4
	Tax revenue	Mio. Euro/a	6.4	-21.6	-24.8	-25.0	-7.7
	Welfare	Mio. Euro/a	55.6	-8.3	-11.7	-14.3	-113.9

As an example to show the differences of the financing options with regard to the socio-economic and environmental impacts, the results for Poland are displayed in Figure 50. In the Full Coop Acc scenario, the impacts on almost all parameters can be both negative and positive depending on the year. This is due to the considerable changes in the economy that are induced by the acceleration of the refurbishment activities.

On average, financing option 1 leads to the best results and financing option 5 scores worst. Only small differences exist between the financing options when compared to the variation of the results between years. Also, financing option 4 leads to acceptable results.

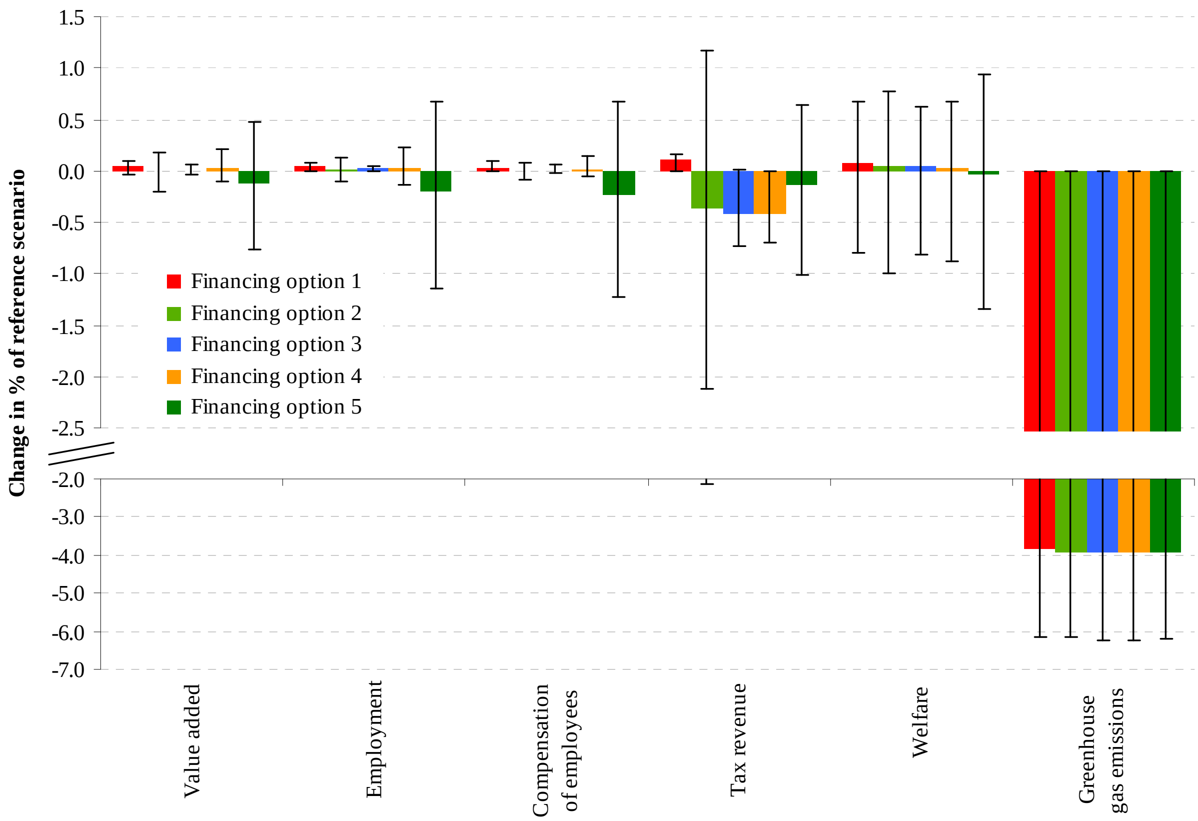

Figure 50 Average changes of the Full Coop Acc scenario compared to the reference scenario from 2000 to 2060 in Poland
The error bars display the range of the effects for all the single years

In the Full Coop Acc scenario, the impacts on individual sectors of the economy can be quite high due to the acceleration of roof and window refurbishment from 2009 to 2018 which leads to high investment in construction-related sectors of the economy (see Section 8.4). In the subsequent years, this investment is significantly decreased. The changes in sectoral output can range from -8.3 % to 10.8 % for financing option 1, all sectors and the years 2000 to 2060 in Germany.

The impacts on sectoral output for the years 2015, 2025, and 2050 for financing option 1 in Germany as an example for the ten most affected sectors of the economy is shown in Figure 51. As a consequence of the acceleration of roof and window refurbishment, considerable increases in the investment in construction-related sectors occur in 2015 (e.g. construction work, mining and quarrying products). The investment in other sectors is reduced (e.g. other transport equipment, computer and related services) because in financing option 1, the GFCF budget is kept constant and the investment is reallocated only. In 2025, we see the opposite picture with the budget for roof and window refurbishment in the reference scenario being reallocated to non-construction related GFCF sectors. These sectors thus face a significant increase in demand while the demand for and the output of construction-related sectors are diminished. Interestingly, the energy savings due to this policy scenario do not play a major role but the impacts on the economy are dominated by changes in the investment.

Due to the abrupt changes in the economy, questions of adaptability arise. Several sectors of the economy will face fast changing business environment, especially when the acceleration periods starts and ends.

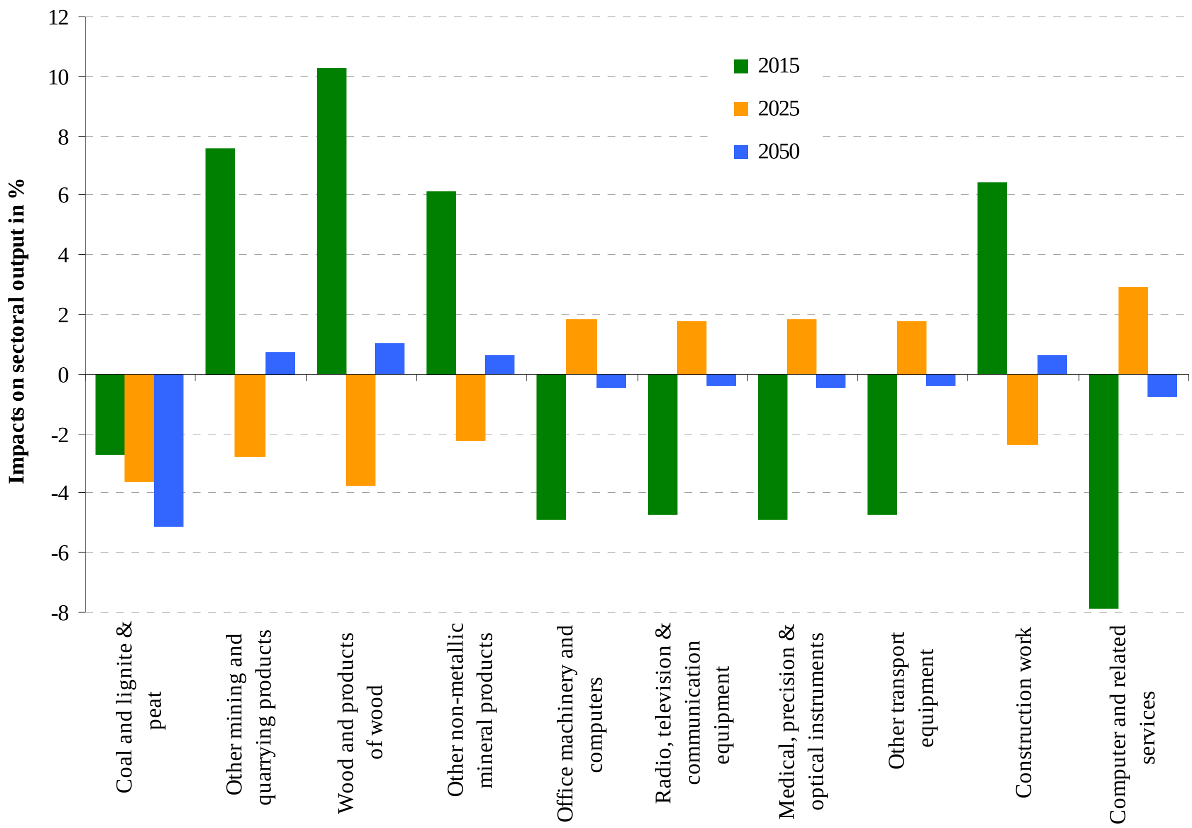

Figure 51 **Impacts on sectoral output for the Full Coop Acc scenario compared to the reference scenario for Germany (financing option 1)**

In Table 50, an overview over the advantages and disadvantages and the main findings with respect to the Full Coop Acc scenario is given. The main advantage of the scenario is the reduction of GHG emissions which is greatest in this scenario compared to all other policy scenarios. Concerning the socio-economic variables, the scenario shows on average very high figures for value added, employment, and compensation of employees but the results for these indicators depend very much on the year under consideration (the results show a very high variation).

Table 50 **Summary of the Full Coop Acc scenario analysis**

Socioeconomic impacts	
+	Best scenarios in terms of GHG emission reductions
+/–	Very high value added scores but high variation (negative impacts can be expected in some years)
+/–	Very high employment scores but high variation (negative impacts can be expected in some years)
+/–	Very high compensation of employment scores but high variation (negative impacts can be expected in some years)
+/–	Intermediate tax revenue scores compared to other scenarios
–	One of the worst scenarios with regards to welfare
–	Abrupt changes/shocks in economy
Policy instruments/measures	
Additional/new policy instrument needed assuring that whenever renovation or refurbishment takes place, the cost optimal EE level is reached (e.g. minimum performance requirements). In addition, financial incentives and/or obligations have to be put in place that the building elements are all retrofitted within the accelerated retrofitting period.	
Financing options	
+	Financing option 1
+/–	Financing options 2 &4
–	Financing option 3 &5

9.3.4 Cost optimal retrofitting of roofs and windows scenario

The cost optimal retrofitting of roofs and windows scenario assumes the energy efficiency levels of roof and windows installed to be the same as in the EPBD Recast scenario until 2013. From 2014 to 2016, the EE levels are partly cost optimal (i.e. increasing share of EE level 3). From 2017 on, only EE level 3 is installed. The summarised results of this policy scenario are presented in Table 51.

With respect to the different financing options, only one clear conclusion can be drawn: Financing option 1 leads to the best results for all indicators except for GHG emissions (see Section 7.3). The ranking of the other financing options depends on the country and parameter you look at.

Table 51 Results for the Coop RR&WR scenario compared to reference scenario (average from 2000 to 2060)

Country	Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5
Germany	Value added	Mio. Euro/a	607.9	253.1	233.4	190.9	-148.4
	Employment	1 000 Employees/a	17.8	9.7	9.1	8.3	-4.7
	Compensation of employees	Mio. Euro/a	117.2	88.9	102.2	72.0	-448.4
	GHG reductions	Mt CO_2-eq. /a	16.8	17.0	17.0	17.0	17.0
	Tax revenue	Mio. Euro/a	131.1	19.3	7.7	-2.0	119.6
	Welfare	Mio. Euro/a	452.1	217.5	220.9	165.6	-206.5
Spain	Value added	Mio. Euro/a	334.1	292.8	73.6	147.4	262.3
	Employment	1 000 Employees/a	63.1	56.8	22.8	24.3	54.2
	Compensation of employees	Mio. Euro/a	161.6	141.7	36.2	84.2	105.5
	GHG reductions	Mt CO_2-eq. /a	5.3	5.4	5.9	5.8	5.4
	Tax revenue	Mio. Euro/a	50.7	32.2	-69.6	-64.6	41.8
	Welfare	Mio. Euro/a	810.1	766.8	541.1	583.2	740.1
Poland	Value added	Mio. Euro/a	34.4	22.6	3.9	22.0	-17.2
	Employment	1 000 Employees/a	2.3	1.8	1.0	2.7	-3.1
	Compensation of employees	Mio. Euro/a	8.8	3.5	-4.8	6.5	-36.6
	GHG reductions	Mt CO_2-eq. /a	4.4	4.4	4.4	4.4	4.4
	Tax revenue	Mio. Euro/a	4.7	-4.5	-20.8	-20.1	-0.1
	Welfare	Mio. Euro/a	181.3	160.3	126.3	135.1	125.6

With only a few exceptions, the results range from negative to positive impacts for all financing options except for greenhouse gas emissions where only reductions occur (Figure 52). Again, the variation of the results is greater over the years than between the individual financing options for most of the indicators.

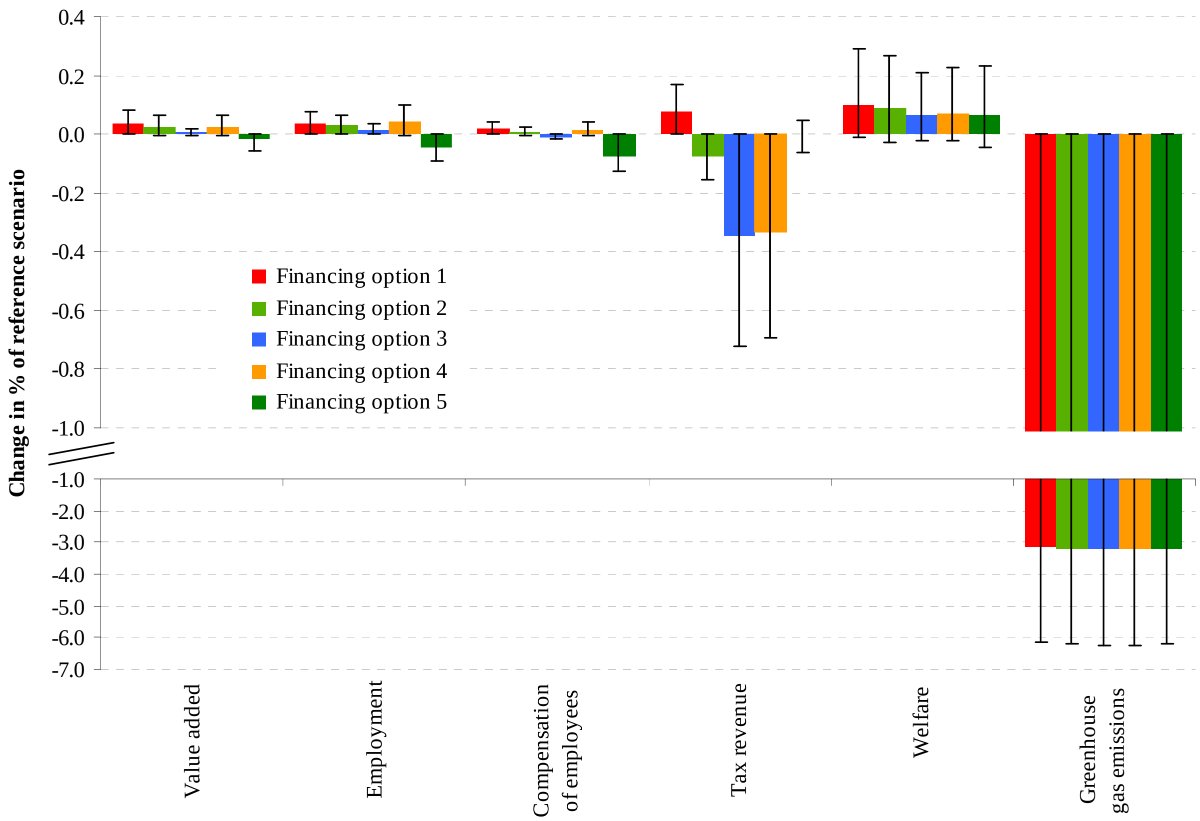

Figure 52 **Average changes of the Coop RR&WR scenario compared to the reference scenario from 2000 to 2060 in Poland**
The error bars display the range of the effects for all the single years

The ten most affected sectors of the economy in the Coop RR&WR scenario are the same than in the EPBD recast and Full Coop scenarios for Germany (Figure 53). The range of the sectoral changes is small (-5.2 % to 1.4 % for all sectors and years between 2000 and 2060 for financing option 1).

The pattern of the sectoral impacts is similar to the EPBD recast and Full Coop scenarios which are non-accelerated scenarios, too. The energy related sectors face a demand drop due to energy savings in the households (e.g. the sector electrical energy, gas, steam and hot water). The saved energy cost is spent on other consumption items but the impacts on these sectors are lower: the amount is reallocated to many sectors according to the initial expenditure share, thus, relative impacts in a single sector is small. At the same time, the expenses for refurbishment (and – to a minor extent – also for renovation) is increased compared to the reference scenario. The construction-related GFCF sectors will experience an increase in demand (e.g. the sectors construction work or wood and products of wood). The investment in other GFCF sectors which are not related to construction will decrease (e.g. office machinery and computers). However, there will not be any abrupt changes in the economy as it is the case for scenarios which imply an acceleration of refurbishment activity.

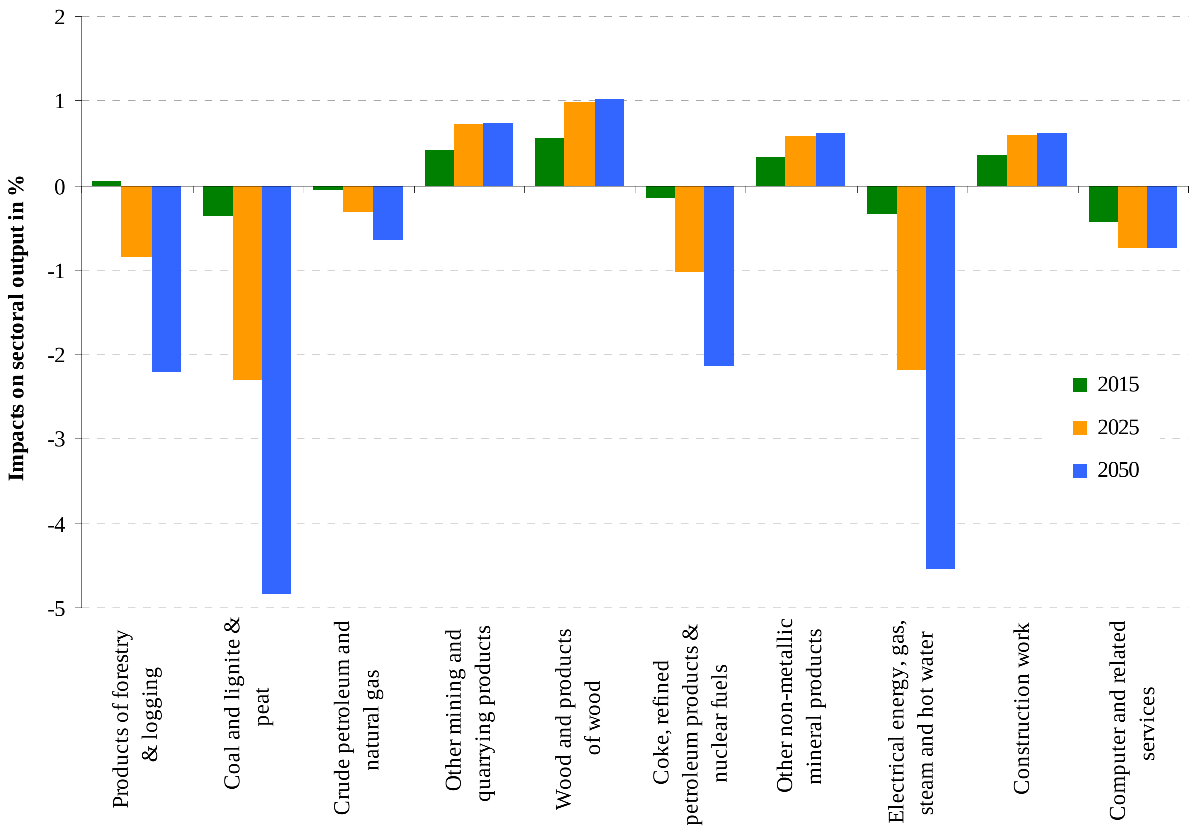

Figure 53 **Impacts on sectoral output for the Coop RR&WR scenario compared to the reference scenario for Germany (financing option 1)**

The Coop RR&WR scenario offers several advantages: it compares quite well with respect to GHG emission savings and it does not lead to significant negative welfare effects (see Section 9.2.5). In addition, there are no abrupt changes as the scenario does not imply acceleration measures (Table 52). However, the scenario scores not very well with respect to value added and employment.

Table 52 **Summary of the Coop RR&WR scenario analysis**

Socioeconomic impacts	
+	No abrupt changes/shocks in economy
+	Second best scenario with regards to welfare
+/–	Fifth best scenarios in terms of GHG emission reductions
+/–	Intermediate tax revenue scores compared to other scenarios
–	Low value added scores compared to other scenarios
–	Low employment scores compared to other scenarios
–	Low compensation of employees scores compared to other scenarios
Policy instruments/measures	
Additional/new policy instrument needed assuring that whenever refurbishment of single building elements takes place, the cost optimal EE level is reached (e.g. minimum performance requirements).	
Financing options	
+	Financing option 1
+/–	Financing options 2-5 (depending on indicator and country)

9.3.5 Accelerated cost optimal retrofitting of roofs & windows scenario

This scenario is based on the cost optimal retrofitting of roofs & windows scenario (see Section 9.3.4) and includes an acceleration of both, roof retrofitting and window retrofitting between 2014 and 2023. It is assumed that by 2023, all roofs and windows have to achieve the cost optimal energy efficiency level 3. In Table 53, an overview over the results for this scenario is given.

Interestingly, this scenario leads to very different results with regards to the single countries. In Spain, on average, the socio-economic impacts are positive for the majority of the financing options and parameters. For Germany, this policy scenario leads to a significant welfare loss in all financing options. In Poland, both welfare and tax revenue are reduced, in general.

Table 53 Results for the Coop Acc RR&WR scenario compared to reference scenario (average from 2000 to 2060)

Country	Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5
Germany	Value added	Mio. Euro/a	1175.6	-18.3	751.4	838.2	-1190.9
	Employment	1 000 Employees/a	34.9	8.6	25.1	26.9	-34.3
	Compensation of employees	Mio. Euro/a	320.5	187.9	296.8	438.9	-1421.8
	GHG reductions	Mt CO_2-eq. /a	17.9	18.6	18.2	18.1	18.8
	Tax revenue	Mio. Euro/a	154.6	-202.1	18.5	63.3	119.9
	Welfare	Mio. Euro/a	-2492.2	-3241.0	-2749.1	-2596.2	-4590.5
Spain	Value added	Mio. Euro/a	395.4	275.0	101.5	162.0	188.9
	Employment	1 000 Employees/a	74.5	56.4	29.2	30.1	49.0
	Compensation of employees	Mio. Euro/a	193.9	136.0	52.5	91.7	33.1
	GHG reductions	Mt CO_2-eq. /a	5.8	6.0	6.4	6.4	6.0
	Tax revenue	Mio. Euro/a	60.5	7.3	-74.5	-71.4	35.1
	Welfare	Mio. Euro/a	736.8	611.8	434.2	462.4	534.8
Poland	Value added	Mio. Euro/a	36.6	-3.4	2.5	16.9	-118.9
	Employment	1 000 Employees/a	2.8	1.0	1.3	2.0	-13.5
	Compensation of employees	Mio. Euro/a	16.6	-1.4	1.4	7.2	-118.9
	GHG reductions	Mt CO_2-eq. /a	4.7	4.8	4.8	4.8	4.8
	Tax revenue	Mio. Euro/a	5.8	-22.4	-21.8	-22.2	-8.4
	Welfare	Mio. Euro/a	14.9	-49.5	-44.7	-49.7	-156.1

With only a few exceptions, the results range from negative to positive impacts for all financing options except for greenhouse gas emissions where only reductions occur (Figure 54). Again, the variation of the results is greater over the years than between the individual financing options for most of the indicators like it is the case for the Full Coop Acc scenario (see Section 9.3.3). This is caused by the significant changes in the economy that are induced by the acceleration of the refurbishment activities.

In Germany, on average, financing option 1 (constant household and GFCF budget) leads to the best results while option 4 also shows good figures on average. Financing option 5 scores worst concerning all parameters except GHG emission reduction.

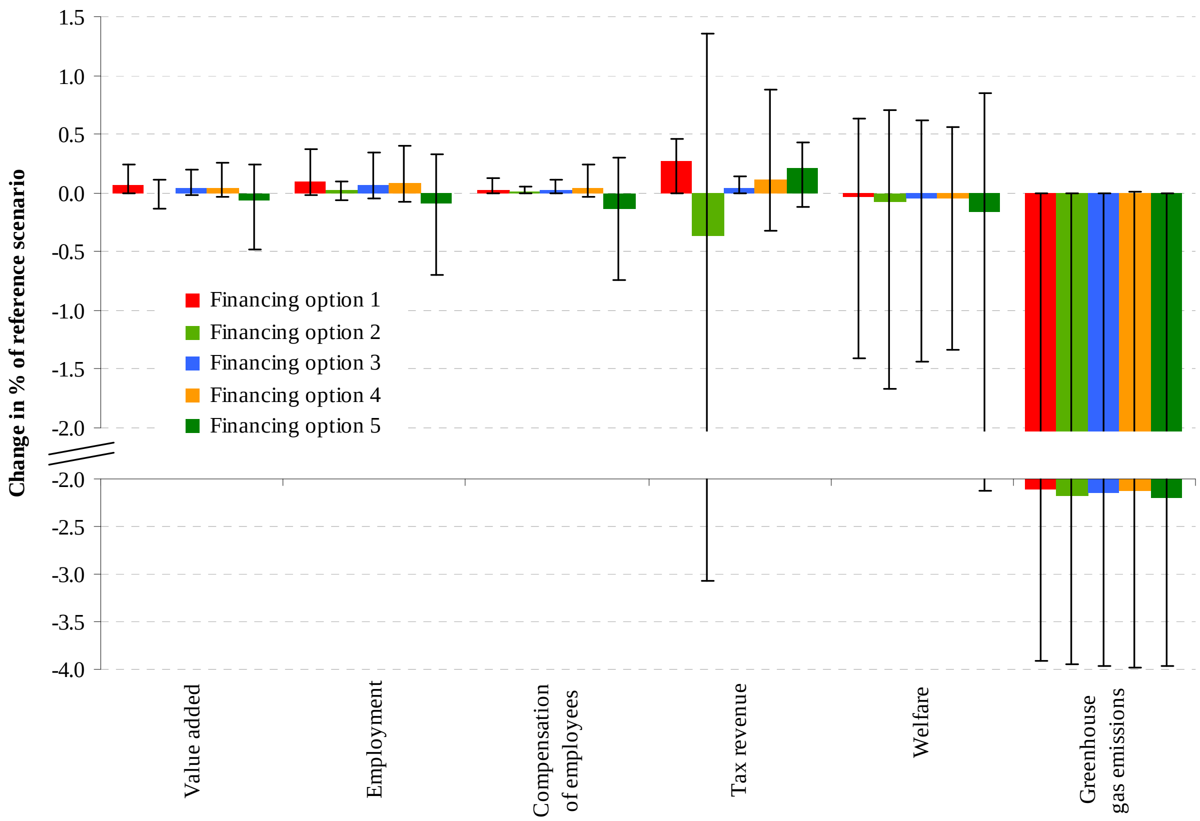

Figure 54 **Average changes of the Coop Acc RR&WR scenario compared to the reference scenario from 2000 to 2060 in Germany**
The error bars display the range of the effects for all the single years

The impacts on individual sectors of the economy are similar to the Full Coop Acc scenario (Section 9.3.3). Again, the impacts on individual sectors of the economy can be substantial due to the acceleration of roof and window refurbishment. The changes in sectoral output can range from -10.4 % to 13.5 % for financing option 1, all sectors and the years 2000 to 2060 in Germany and thus even exceed the range of the Full Coop Acc scenario.

As an example, the impacts on sectoral output for the years 2015, 2025, and 2050 for financing option 1 in Germany as an example for the ten most affected sectors of the economy is shown in Figure 55. The faster replacement of roofs and window leads to an increase in the investment in construction-related sectors in 2015. At the same time, the investment in other sectors is reduced (e.g. other transport equipment, computer and related services). In 2025, when there is no acceleration, the expenditure for refurbishment activities is being reallocated to non-construction related sectors which increase output. Also in this scenario, the energy savings are of minor importance compared to the changes in investment.

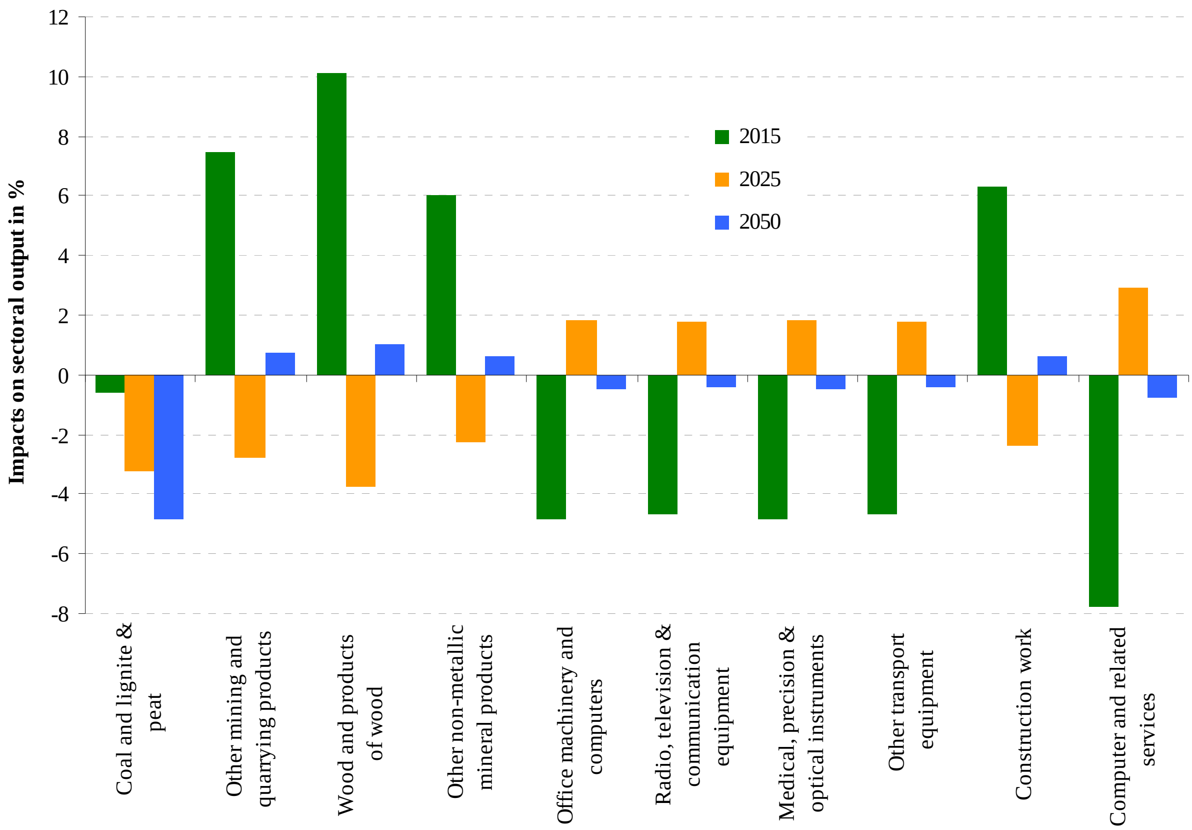

Figure 55 **Impacts on sectoral output for the Coop Acc RR&WR scenario compared to the reference scenario for Germany (financing option 1)**

In Table 54, the results for the Coop Acc RR&WR policy scenario are summarised. The scenario leads to high GHG emission reductions compared to other scenarios. With respect to the socio-economic impacts, the results show a very high variation. In addition, the scenario leads to adverse welfare effects.

Table 54 **Summary of the Coop Acc RR&WR scenario analysis**

Socioeconomic impacts

+	High value added scores but high variation (negative impacts can be expected in some years)
+	High employment scores but high variation (negative impacts can be expected in some years)
+	High compensation of employment scores but high variation (negative impacts can be expected in some years)
+/–	Third best scenario in terms of GHG emission reductions
+/–	Intermediate tax revenue scores compared to other scenarios
–	Abrupt changes/shocks in economy
–	Worst scenario with regards to welfare

Policy instruments/measures

Additional/new policy instrument needed assuring that whenever refurbishment takes place, the cost optimal EE level is reached (e.g. minimum performance requirements). In addition, financial incentives and/or obligations have to be put in place that the building elements are all retrofitted within the accelerated retrofitting period.

Financing options

+	Financing option 1
+/–	Financing options 2-5 (depending on indicator and country)

9.3.6 Accelerated cost optimal retrofitting of roofs scenario

This policy scenario is similar to the accelerated cost optimal retrofitting of roofs & windows scenario but only roofs and not windows are replaced faster. The results of the analysis show that

In Table 55, an overview over the results for this scenario is given. The results are similar to the scenario with both acceleration of windows and roofs. Obviously, the greenhouse gas reductions are smaller when only roofs are replaced. The average socio-economic impacts are smaller, too. For a majority of the financing options and parameters, the impacts are positive on average. Especially with regards to welfare effects, the scenario scores better compared to the acceleration of both roof and window retrofitting.

Table 55 Results for the Coop Acc RR scenario compared to reference scenario (average from 2000 to 2060)

Country	Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5
Germany	Value added	Mio. Euro/a	757.1	42.1	399.2	420.4	-728.4
	Employment	1 000 Employees/a	23.1	7.0	14.8	15.3	-20.8
	Compensation of employees	Mio. Euro/a	162.6	97.3	146.0	204.8	-942.3
	GHG reductions	Mt CO_2-eq. /a	15.6	16.1	15.9	15.8	16.2
	Tax revenue	Mio. Euro/a	127.4	-93.7	10.7	28.7	105.3
	Welfare	Mio. Euro/a	-1052.4	-1516.6	-1271.8	-1218.8	-2354.9
Spain	Value added	Mio. Euro/a	304.1	231.5	72.6	125.8	178.2
	Employment	1 000 Employees/a	57.6	46.6	21.9	22.8	42.0
	Compensation of employees	Mio. Euro/a	148.4	113.5	37.0	71.8	50.2
	GHG reductions	Mt CO_2-eq. /a	4.6	4.8	5.1	5.1	4.7
	Tax revenue	Mio. Euro/a	46.6	14.2	-60.0	-56.8	31.1
	Welfare	Mio. Euro/a	632.7	556.6	394.0	421.9	509.7
Poland	Value added	Mio. Euro/a	29.2	6.4	0.2	10.6	-66.8
	Employment	1 000 Employees/a	2.2	1.1	0.9	1.8	-8.0
	Compensation of employees	Mio. Euro/a	10.3	0.1	-2.6	3.3	-73.8
	GHG reductions	Mt CO_2-eq. /a	4.1	4.1	4.2	4.2	4.2
	Tax revenue	Mio. Euro/a	4.6	-12.6	-19.3	-19.2	-4.2
	Welfare	Mio. Euro/a	84.8	45.6	33.3	34.7	-19.3

Figure 56 shows as an example the results of the socio-economic assessment for Spain. For almost all parameters and financing options, the impacts can be both negative and positive depending on the year which is again caused by the changes in the economy that are induced by the acceleration of the roof refurbishment.

On average, the financing options 1, 2 and 4 show the best results (see Section 7.3). In general, the financing options 3 and 5 score worst. However, the differences between the individual financing options are small compared to the variation of the results over the years.

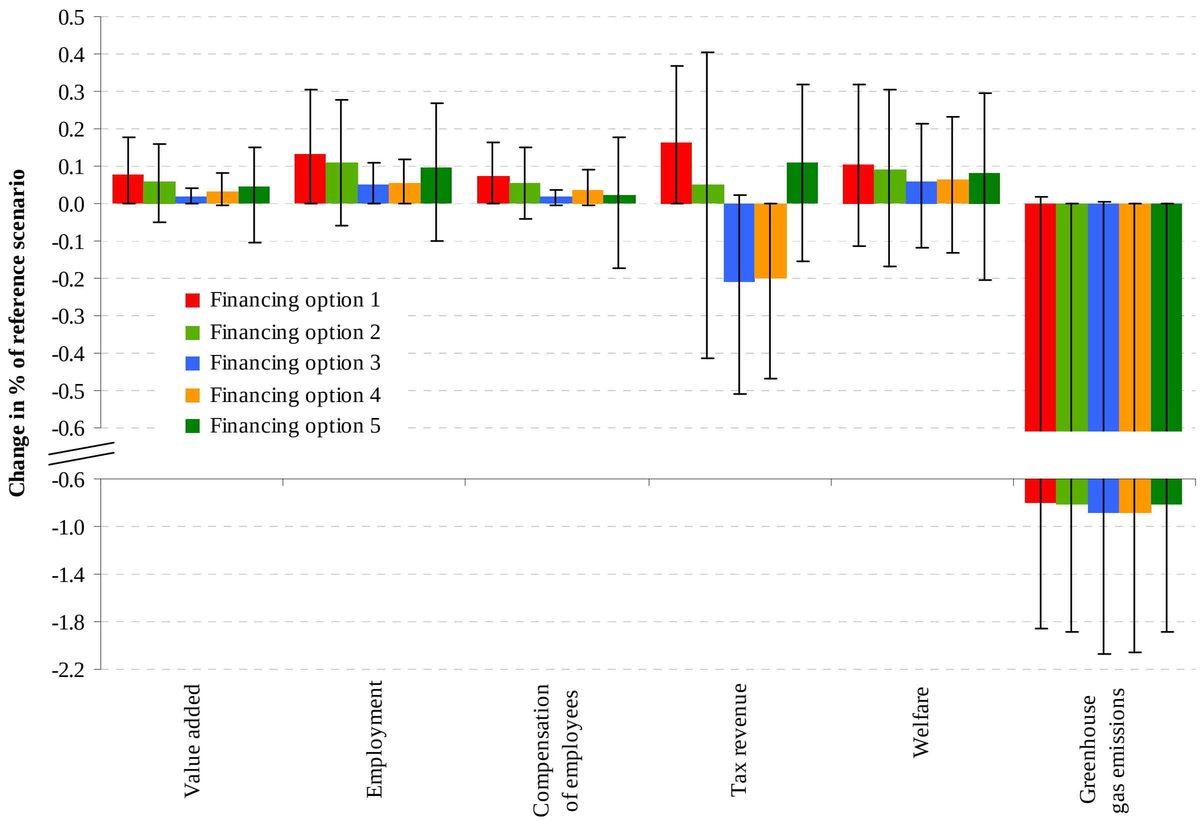

Figure 56 **Average changes of the Coop Acc RR scenario compared to the reference scenario from 2000 to 2060 in Spain**
The error bars display the range of the effects for all the single years

The advantages and disadvantages of the policy scenario are displayed in Table 56. What seem most striking are the negative welfare impacts which indicate a low cost efficiency of this measure in general. However, there exist considerable differences between the countries which does not allow for general conclusions or policy recommendations.

Table 56 **Summary of the Coop Acc RR scenario analysis**

Socioeconomic impacts	
+/–	Intermediate to low value added scores but high variation (negative impacts can be expected in some years)
+/–	Intermediate employment scores but high variation (negative impacts can be expected in some years)
+/–	Intermediate compensation of employment scores but high variation (negative impacts can be exp. in some years)
+/–	Intermediate tax revenue scores compared to other scenarios
–	Low GHG emission reductions
–	Abrupt changes/shocks in economy
–	Negative welfare effects
Policy instruments/measures	
Additional/new policy instrument needed assuring that whenever roof refurbishment takes place, the cost optimal EE level is reached (e.g. minimum performance requirements). In addition, financial incentives and/or obligations have to be put in place that roofs are all retrofitted within the accelerated retrofitting period.	
Financing options	
+	Financing option 1
+/–	Financing options 2-4 (depending on indicator and country)
–	Financing option 5

9.3.7 Accelerated cost optimal retrofitting of windows scenario

This policy scenario is similar to the accelerated cost optimal retrofitting of roofs scenario (see Section 9.3.6). However, this time, the replacement of windows is accelerated. Table 57 summarises the results for this scenario. The results are comparable to the scenario with both acceleration of windows and roofs and the scenario with only faster replacement of roofs.

The greenhouse gas reductions are smaller compared to the Coop Acc RR&WR (accelerated replacement of roofs and windows) scenario but higher than in the Coop Acc RR scenario. From an environmental point of view it is thus advantageous first to accelerate the replacement of windows than the replacement of roofs.[23]

With respect to the average socio-economic impacts, the scenario is favourable compared to the faster replacement of roofs for most of the financing options and parameters. Again, especially with regards to welfare effects, the scenario scores better compared to the acceleration of both roof and window retrofitting. However, it has to be noted, that the evaluation of this scenario is very much dependent on the country, the socio-economic parameter, and the financing option.

Table 57 Results for the Coop Acc WR scenario compared to reference scenario (average from 2000 to 2060)

Country	Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5
Germany	Value added	Mio. Euro/a	831.3	76.3	434.6	452.3	-730.2
	Employment	1 000 Employees/a	25.1	8.2	15.9	16.4	-21.0
	Compensation of employees	Mio. Euro/a	182.4	112.0	163.7	219.6	-977.9
	GHG reductions	Mt CO_2-eq. /a	17.3	17.7	17.5	17.5	17.9
	Tax revenue	Mio. Euro/a	140.9	-91.8	11.7	28.8	117.6
	Welfare	Mio. Euro/a	-1010.1	-1498.6	-1252.9	-1205.1	-2380.4
Spain	Value added	Mio. Euro/a	359.4	277.4	85.8	150.4	217.5
	Employment	1 000 Employees/a	67.9	55.5	25.7	26.8	50.4
	Compensation of employees	Mio. Euro/a	175.3	135.8	43.6	85.7	64.6
	GHG reductions	Mt CO_2-eq. /a	5.4	5.6	6.1	6.0	5.6
	Tax revenue	Mio. Euro/a	54.9	18.4	-71.0	-67.1	37.4
	Welfare	Mio. Euro/a	757.1	671.4	475.1	509.1	618.5
Poland	Value added	Mio. Euro/a	33.2	7.6	1.1	13.6	-73.1
	Employment	1 000 Employees/a	2.5	1.3	1.0	2.0	-8.8
	Compensation of employees	Mio. Euro/a	11.8	0.4	-2.5	4.5	-81.3
	GHG reductions	Mt CO_2-eq. /a	4.5	4.6	4.6	4.6	4.6
	Tax revenue	Mio. Euro/a	5.2	-13.9	-21.2	-21.2	-4.6
	Welfare	Mio. Euro/a	93.1	49.5	36.1	37.6	-22.5

The results for the comparison of the financing options with regards to the acceleration of window retrofitting show the same pattern than for the faster replacement of roofs (Figure 57). Again, the impacts can be both negative and positive – depending on the year – for almost all parameters and financing options. Again, financing option 1 scores best and financing options 5 scores worst.

[23] This conclusion is valid for the three countries included in this study. No recommendations can be made with respect to other countries.

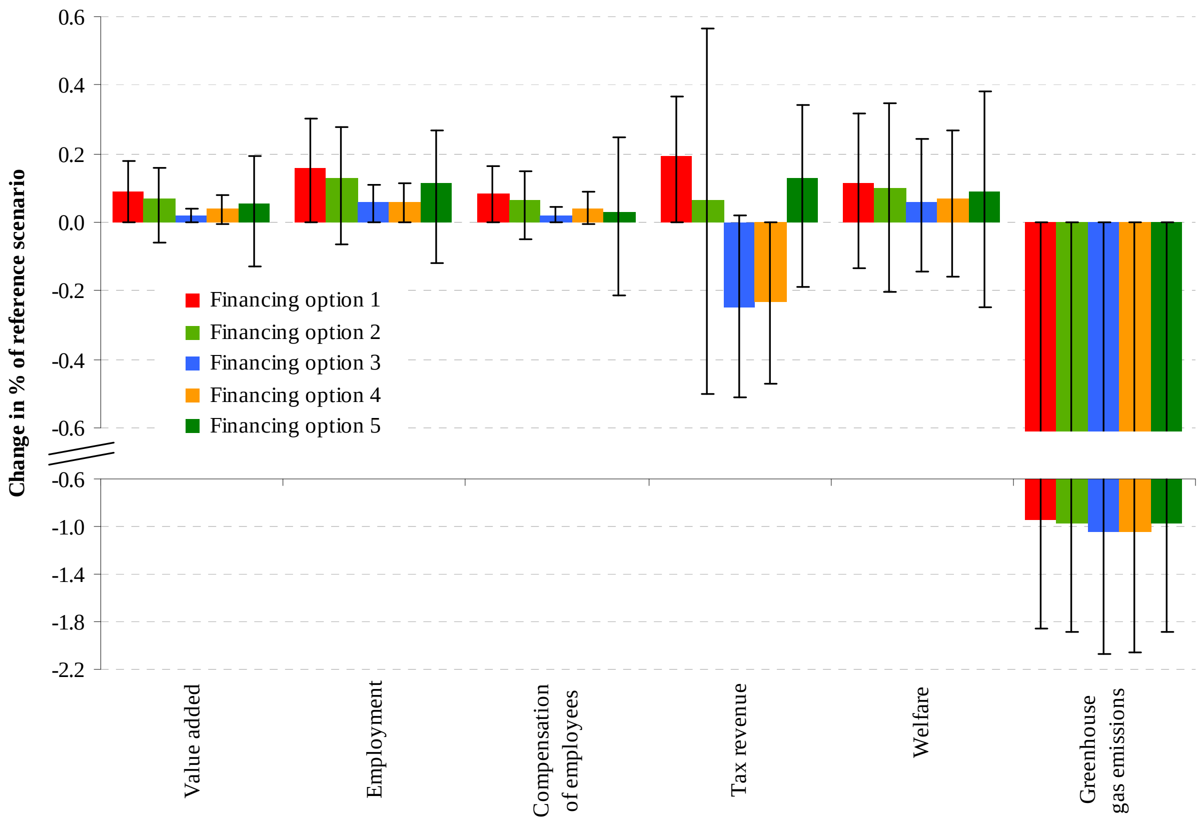

Figure 57 Average changes of the Coop Acc WR scenario compared to the reference scenario from 2000 to 2060 in Spain
The error bars display the range of the effects for all the single years

The summarised results for this policy scenario are shown in Table 58. The welfare effects are slightly better compared to the acceleration of roof refurbishment. Still, the measure seems to be not very cost efficient in general.

Table 58 Summary of the Coop Acc WR scenario analysis

Socioeconomic impacts	
+/–	Intermediate to low value added scores but high variation (negative impacts can be expected in some years)
+/–	Intermediate employment scores but high variation (negative impacts can be expected in some years)
+/–	Intermediate compensation of employment scores but high variation (negative impacts can be exp. in some years)
+/–	Intermediate tax revenue scores compared to other scenarios
+/–	Intermediate results with regards to welfare depending on country
–	Low GHG emission reductions
–	Abrupt changes/shocks in economy
Policy instruments/measures	
Additional/new policy instrument needed assuring that whenever window refurbishment takes place, the cost optimal EE level is reached (e.g. minimum performance requirements). In addition, financial incentives and/or obligations have to be put in place that windows are all retrofitted within the accelerated retrofitting period.	
Financing options	
+	Financing option 1
+/–	Financing options 2-4 (depending on indicator and country)
–	Financing option 5

9.4 Sensitivity analyses

The modelling framework applied in this study implies limitations which have to be kept in mind when interpreting the results (see Section 3.6). Some of the limitations are inherent to the model chosen for the analysis. Others arise from data uncertainty and assumptions that had to be made:

- Assumptions concerning the building stock (e.g. the historical development of the building stock, or the construction:demolition ratio;
- Assumptions on future energy prices and costs for renovation and refurbishment;
- The timing of policy measures.

The influence of these uncertainties have been tested by the means of sensitivity analyses and the results of this study have proven to be quite robust with respect to these types of limitations (see Sections 9.4.1 to 9.4.3). In addition to the sensitivity analyses, a rough assessment of the reduction of ventilation losses which is a very cost-efficient measure [Nemry et al. 2008] that has not been covered by the policy scenarios has been performed (see Section 9.4.4).

9.4.1 Building stock assumptions

Several assumptions concerning the building stock had to be made during the set up of the building stock model influencing the construction of new buildings, and renovation & refurbishment activity (see Chapter 5). The most important parameters are the assumptions on the construction:demolition ratio and the assumptions on the historical development of the buildings stock.

Construction:demolition ratio

The net construction of buildings has been derived from historical data and assumptions on the historical development of the building stock. Gross construction and demolition has then been calculated assuming a construction:demolition ratio of 5. To test the sensitivity of the model with respect to this assumption, the building stock model for Germany was set up also using a ratio of 2 and 10 (which can be seen as extreme cases) in order to show the possible bandwidth of uncertainty.

In Figure 58, the results for gross construction and demolition in Germany are shown. Both gross construction and demolition are increased (by 25 % and 150 %, respectively) in the 2:1 assumption and decreased for the 10:1 assumption (by 8 % and 50 %, respectively). The lower the assumption for the construction:demolition ratio, the higher the turnover of the building stock. This of course, affects renovation activity as shown in Figure 59. Major renovation activity is reduced between 6 % and 58 % - depending on year – in case of a construction:demolition ratio of 2:1. For a construction:demolition ratio of 10:1, the major renovation activity is increased between 2 % and 20 %, depending on the year. Roof and window refurbishment also are affected by the assumption on the construction:demolition ratio, however, the differences between the 2:1, 5:1, and 10:1 options are not so significant as it is the case for major renovation.

When we look at the effects of different assumptions on the construction:demolition ratio on energy demand for space heating by households, we can see that energy demand is increased for a high construction:demolition ratio and decreased for a low ratio due to different turnover of speed of the building stock (Figure 60, top). This applies to all policy scenarios. The energy saving for a policy scenario (i.e. the difference between the scenario and the reference) does not vary much between different assumptions for construction:demolition ratio as shown in Figure 60 (bottom) for the EPBD recast scenario. The relative energy savings for the EPBD recast scenario compared to the reference scenario only deviate by 0.1 % to 0.2 % depending on year and assumption.

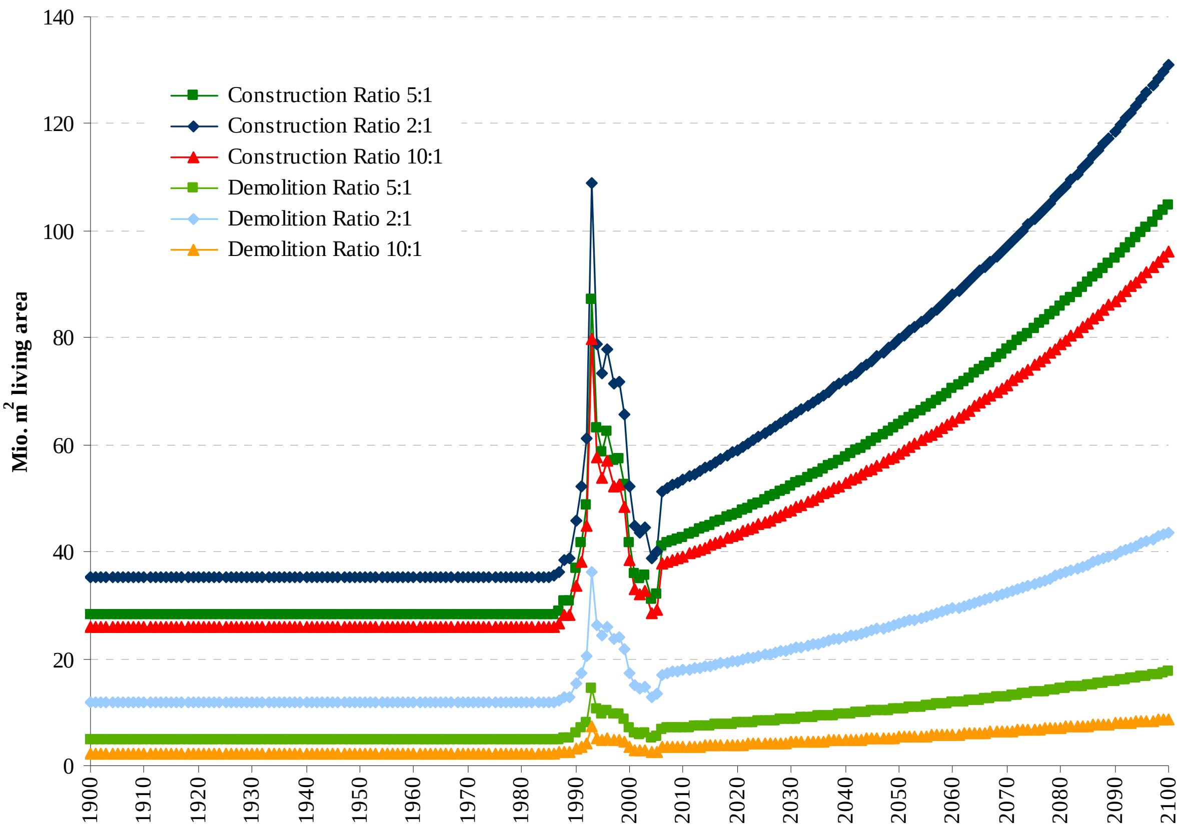

Figure 58 Construction and demolition in Germany for different construction:demolition ratios

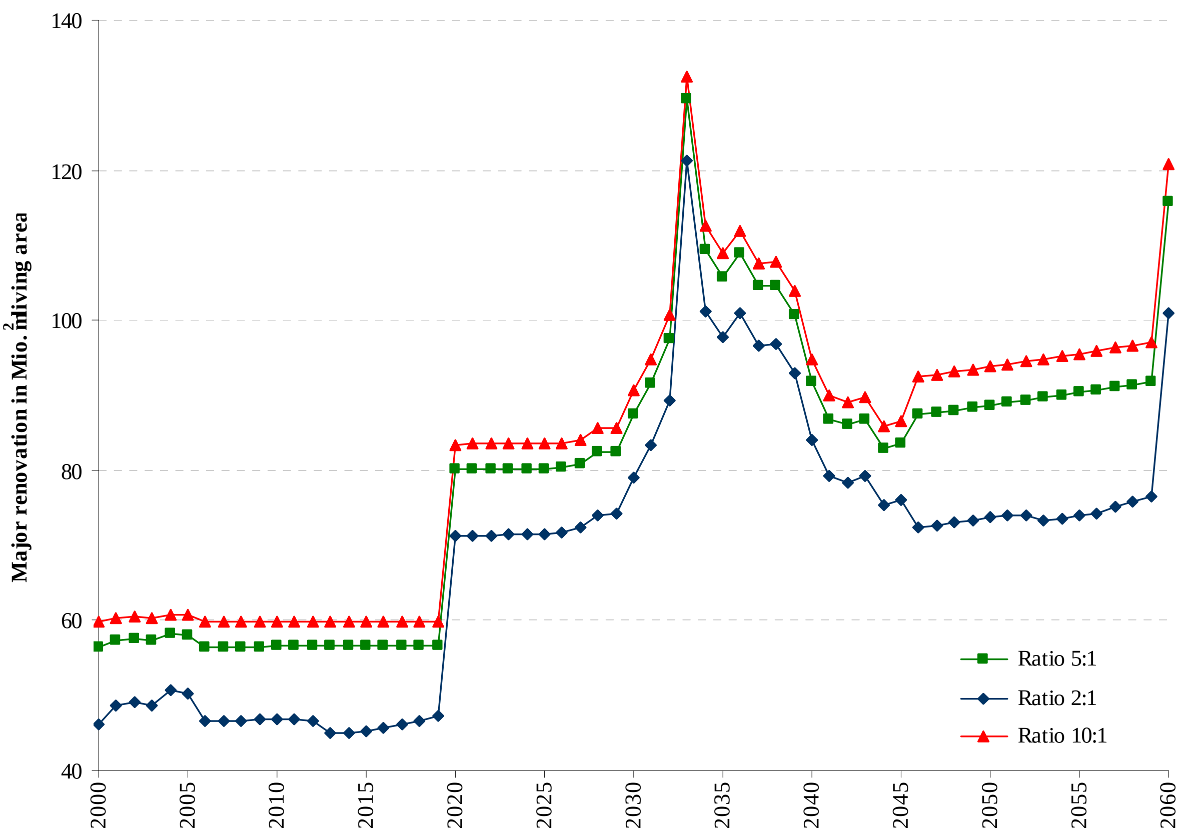

Figure 59 Major renovation in Germany for different construction:demolition ratios

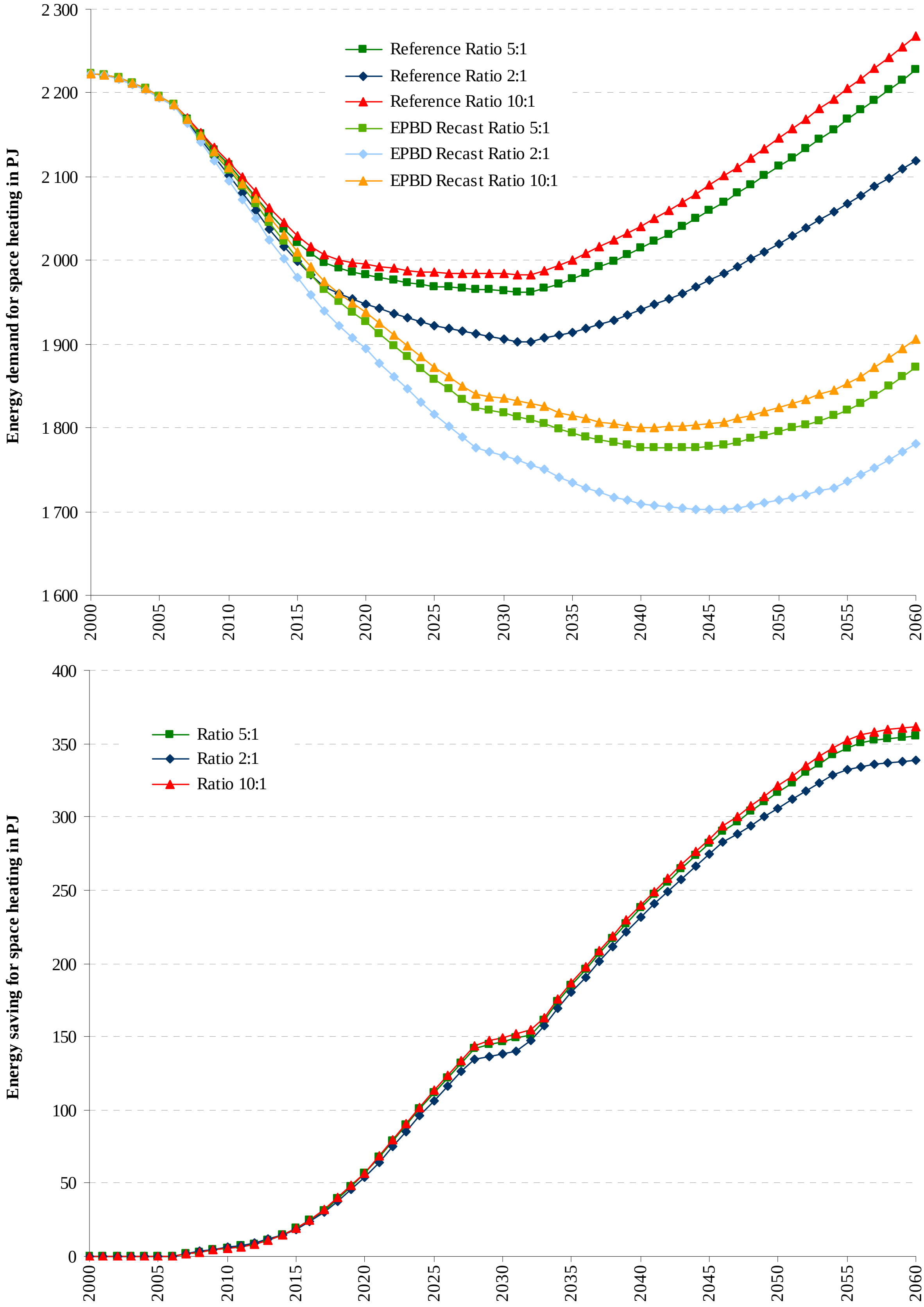

Figure 60 **Energy demand for space heating in Germany for the reference and the EPBD recast scenario (top) and energy saving in the EPBD recast scenario compared to the reference scenario (bottom) for different construction:demolition ratios**

From the sensitivity analyses it can be concluded that the results of the building stock model are quite robust with respect to different assumptions on the construction:demolition ratio. As we compare different policy scenarios to a baseline, we are interested in the differences of the various parameters, e.g. energy demand. The effects of variation in construction:demolition ratio thus is cancelled out.

Historical development of the building stock

Data on the historical building stock was available for Germany from 1986, for Poland from 2002, and for Spain from 1990 to 2006. For the period before data was available, a linear interpolation was done (see Section 5.1). The assumptions on the historical building stock development affects the renovation and refurbishment activities of the building stock as they take place within a 'natural' retrofitting cycle, as said before. To test the sensitivity of the building stock model with respect to the assumptions made on the historical building stock several alternatives were assessed for Germany:

- Assuming a linear increase of the building stock instead of using actual time series data;
- Assuming a linear increase of the building stock with the building stock in 1900 being 50 % of the stock in 2006 (which would mean that construction was lower between 1950-2000);
- Assuming a linear increase of the building stock with the building stock in 1900 being 10%, and in 1950 being 25 % of the stock in 2006 (which would mean that construction activity was higher between 1950-2000).

The building stock development according to the different alternatives assessed is shown in Figure 61 from 1900 to 2100.

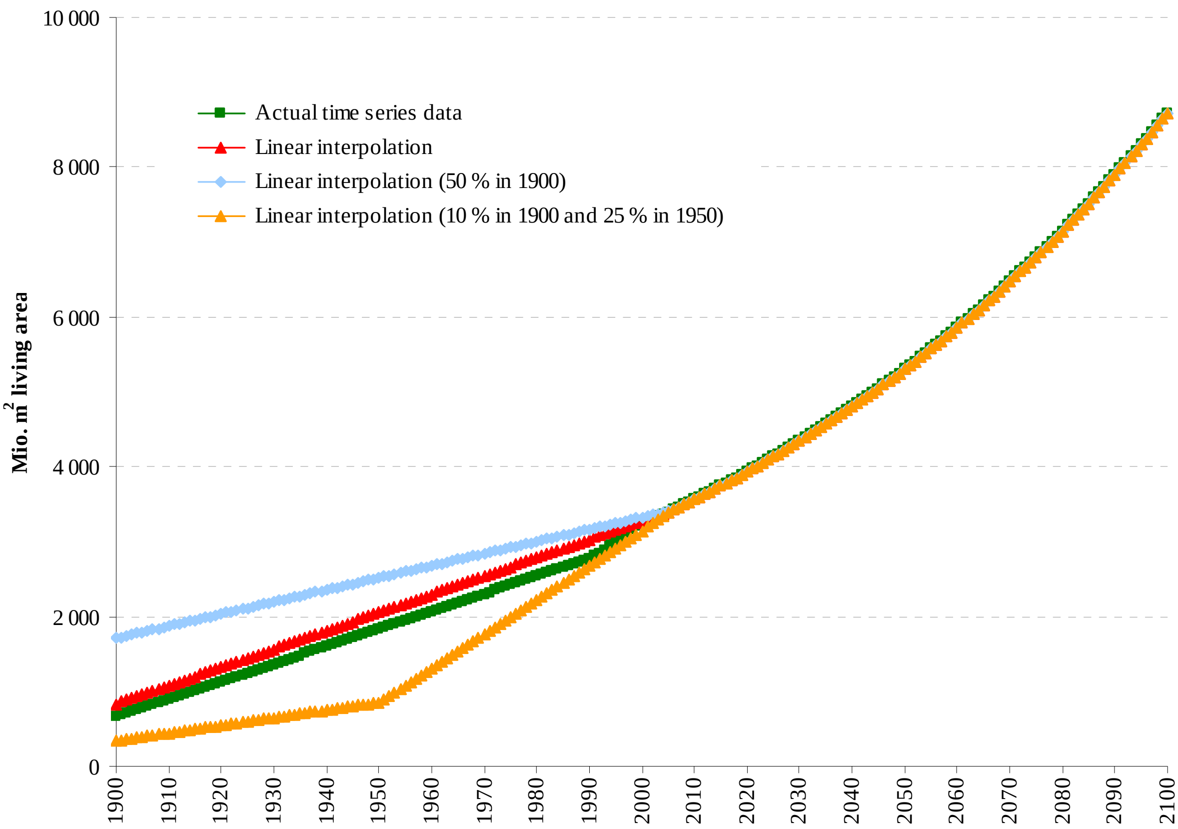

Figure 61 **Building stock in Germany from 1900 to 2100 according to the different assumptions on the historical development of the building stock**

Again, the assumptions on the development of the building stock in the past influence the major renovation activity in the present and in the future (Figure 62). Significant differences can be found for the period from 2020 to 2045, especially. Also, the roof and window refurbishment activity is influenced. Figure 63 shows as an example the results for roof refurbishment in Germany under the different assumptions for the development of the building stock in the past. The differences for the refurbishment of individual building elements are greatest for 2000 to 2025 which is 20 years earlier than in the case of major renovation due to the shorter retrofitting cycle.

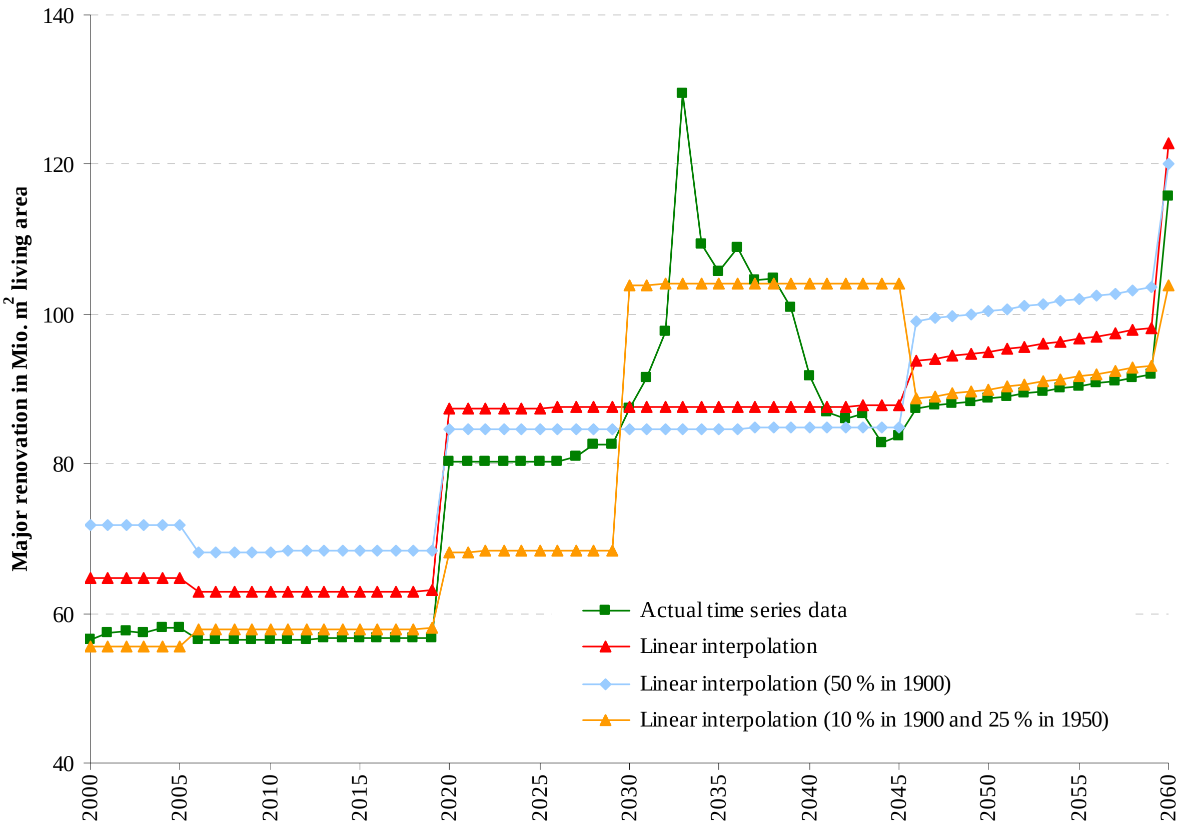

Figure 62 Major renovation in Germany for different assumptions for the development of the building stock in the past (reference scenario)

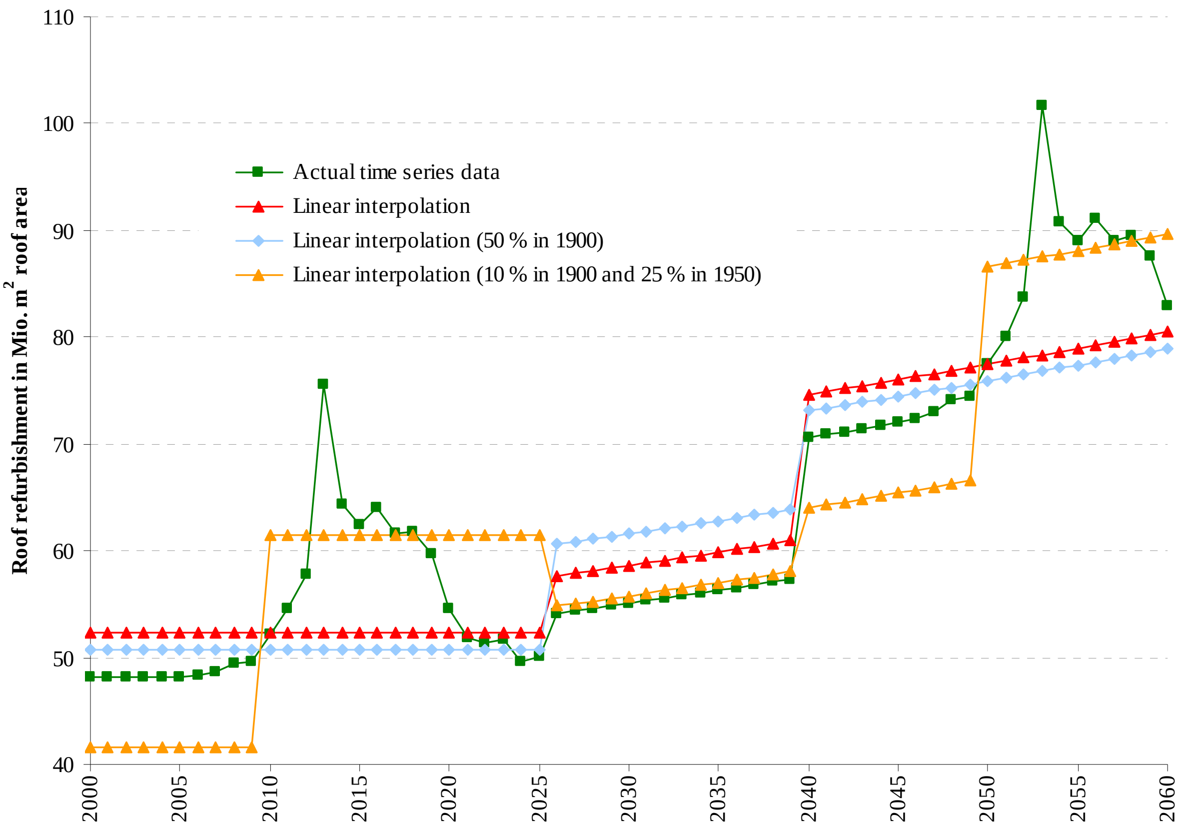

Figure 63 Roof refurbishment in Germany for different assumptions for the development of the building stock in the past (reference scenario)

The energy demand for space heating is influenced by the different assumptions on the development of the building stock (Figure 64, top) Energy demand is lowest when a low building stock was assumed in 1900. This can be explained by faster replacement of the building stock and construction of buildings that show higher energy efficiency level in later years. On the contrary, when it was assumed that a high share of the building stock already existed by 1900, the energy demand is higher between 2000 and 2060. However, the variation in energy demand is very small (between ± 5 %) for all assumptions, and the energy demand converges from 2010 on.

As it was observed for the different assumptions on the construction:demolition ratio (above), the energy saving for a policy scenario (i.e. the difference between the scenario and the reference) does not vary much between different assumptions (Figure 64, bottom). In the case of the Full Coop scenario, the relative energy savings compared to the reference scenario only deviate by a maximum of 0.4 % for all years and the four different assumptions made on the development of the building stock.

We could conclude then, that the results of the building stock model are very robust with respect to different assumptions on the historical building stock. A possible extension of the model could also be done without retrieving additional assumptions on the real development of the building stock but just by assuming linear growth. It has to be kept in mind however, that this only holds true for the comparison of different policy scenarios or the comparison to a baseline and not for absolute values of the results which might differ quite substantial for different assumptions on the development of the building stock.

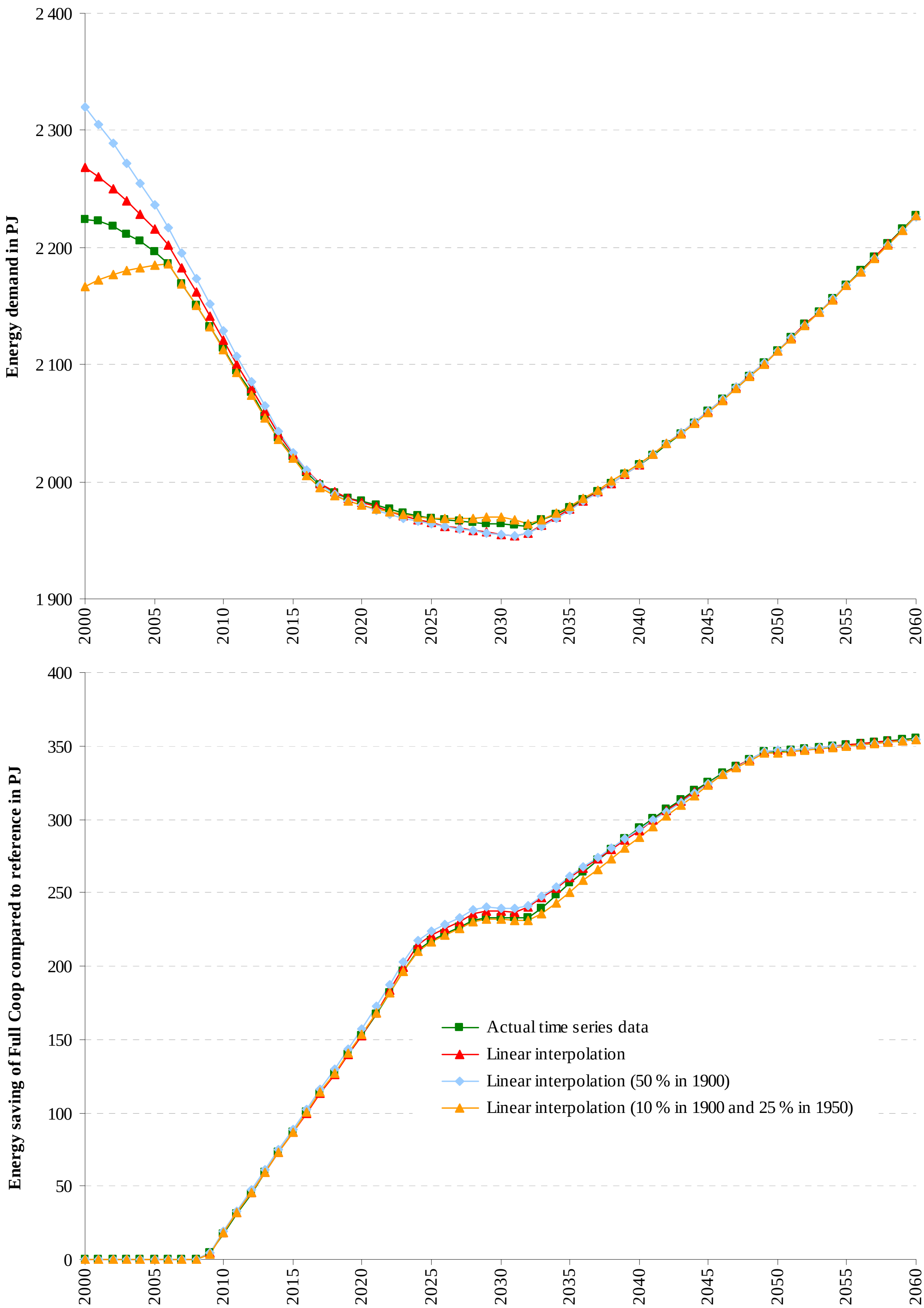

Figure 64 **Energy demand for space heating in Germany for the reference scenario (top) and energy saving in the Full Coop scenario compared to the reference scenario (bottom) for different assumptions for the development of the building stock in the past**

9.4.2 Energy prices and refurbishment costs

A high uncertainty arises from the assumptions made on energy prices and the costs for renovation and refurbishment measures (Chapter 6). It was assumed, that prices will be constant in future, i.e. the calculations were performed in Euro$_{2000}$ as the input-output model also refers to the year 2000. To determine the bandwidth of the net costs for households of the measure, we run the model for several variants on price development from 2000 on:

- Annual energy price increase of 0 %, 1 %, and 2 %;
- Annual price increase for renovation and refurbishment measures of 0 %, 1 %, and 2 %.[24]

The net costs of all possible combination of these estimated price increases were calculated. The results for the nine different variants are displayed in Figure 65 for the EPBD recast scenario (base case) in Germany. Clearly, for the majority of the variants, the net costs are negative, on average. The break-even point varies according to the assumption made on the price development. When the annual costs for renovation and refurbishment increase faster than the energy price, the net costs are positive.

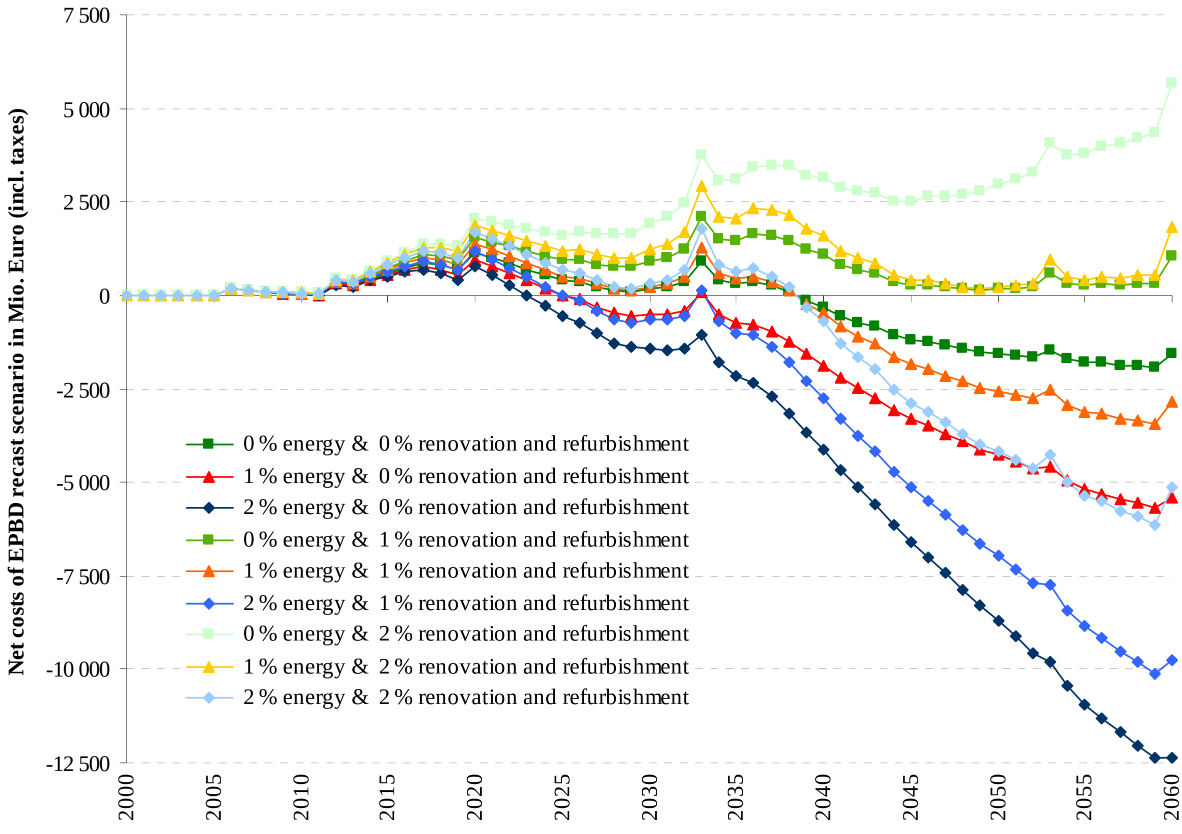

Figure 65 Net costs of the EPBD recast scenario according to different assumptions on price developments for Germany

The net costs of the same nine different variants have been calculated for the Full Coop scenario in Spain, too (Figure 66). The results are similar to the calculations for the EPBD recast scenario in Germany. For the majority of variants, the net costs are negative indicating that the measure pays off

[24] The same annual price increase was assumed for roof refurbishment, window refurbishment and major renovation.

for households. Again, for the three variants which imply a higher annual increase of the costs for renovation and refurbishment than the increase of the energy price, the net costs are positive.

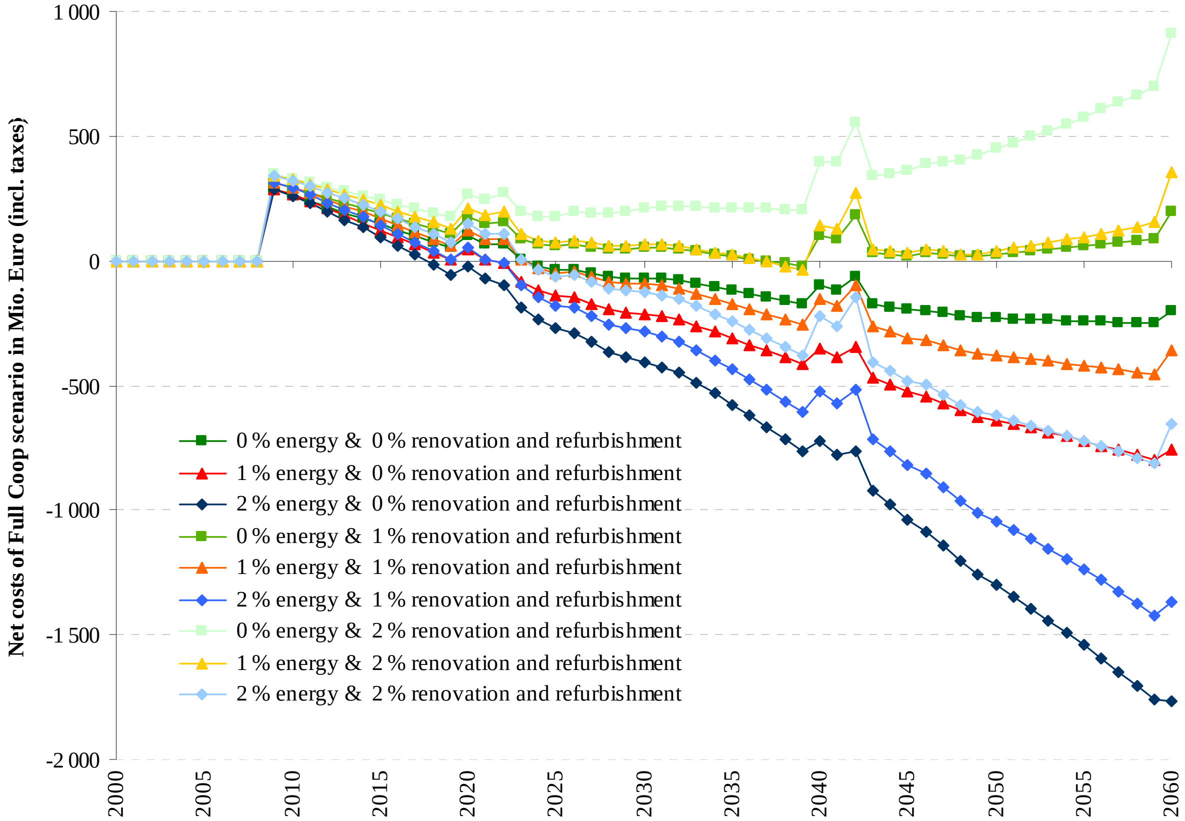

Figure 66 Net costs of the Full Coop scenario according to different assumptions on price developments for Spain

However, according to the Federal Statistical Office Germany, the annual increase of the consumer price index for electricity, gas, and other fuels was about 2.5 % between 1991 and 2004 [Destatis 2004]. The annual price increase of materials and services for the regular maintenance and repair of dwellings was about 1.6 % between 1991 and 2004 [Destatis 2004].

In the EU, the annual increase of consumer prices for heating energy was about 5 % between 1997 to 2008 [Eurostat 2009b]. The consumer price of materials and services for the regular maintenance and repair of dwellings increased by about 2.1 % (materials) to 3.4 % (services) annually between 1997 and 2008 [Eurostat 2009b]. It is thus very probable that the annual energy price increase will be at least as high as the price increase for renovation & refurbishment activities. We are thus confident that the results of our study are quite robust with respect to future price changes and that the conclusions are valid for a broad range of possible price developments.

9.4.3 Timing of policy measures

The adequate timing of the policy measures is important with respect to both environmental and socio-economic impacts. For example, when cost optimal renovation and refurbishment of the building stock takes place within the 'natural' retrofitting cycles, the renovation/refurbishment activity depends on the building stock development. When a high share of the building stock was built 40 years before the measure applies, a high renovation and refurbishment rate can be expected; when the share of building stock built 20 years ago was high, the refurbishment of roofs and windows activity will be high. In the Full Coop scenario, it was assumed that the renovation and refurbishment will be according to cost optimal levels from 2009 on. As in Germany, in the mid 90s the building activity was significantly high than in the years before (due to the modernisation of the building stock in Easter Germany), we can see a peak in refurbishment between 2010 and 2020 (see Figure 21). If cost optimal refurbishment starts later, a high share of the building stock will only undergo a refurbishment 20 years later (2030 to 2040), thus, a considerable improvement potential might be missed. However, one could also imagine the opposite case with policy measures coming too early. It is thus worth exploring different timing of policy measures in terms of cost efficiency.

To give an indication of the probable consequences, we calculated as an example the Full Coop scenario in Germany with beginning of cost optimal renovation and refurbishment only from 2012, 2014, or 2016 instead of 2009 on.

The ‘delay’ of the implementation of the measure leads to a reduction of the initial energy saving potential (Figure 67). However, the energy saving converges for the four options analysed by 2055 to 2060. The cumulative energy saving potential is 8 %, 13 %, and 18 % lower for implementation in 2012, 2014, and 2016, respectively. Consequently, the same applies for the related greenhouse gas emissions reductions.

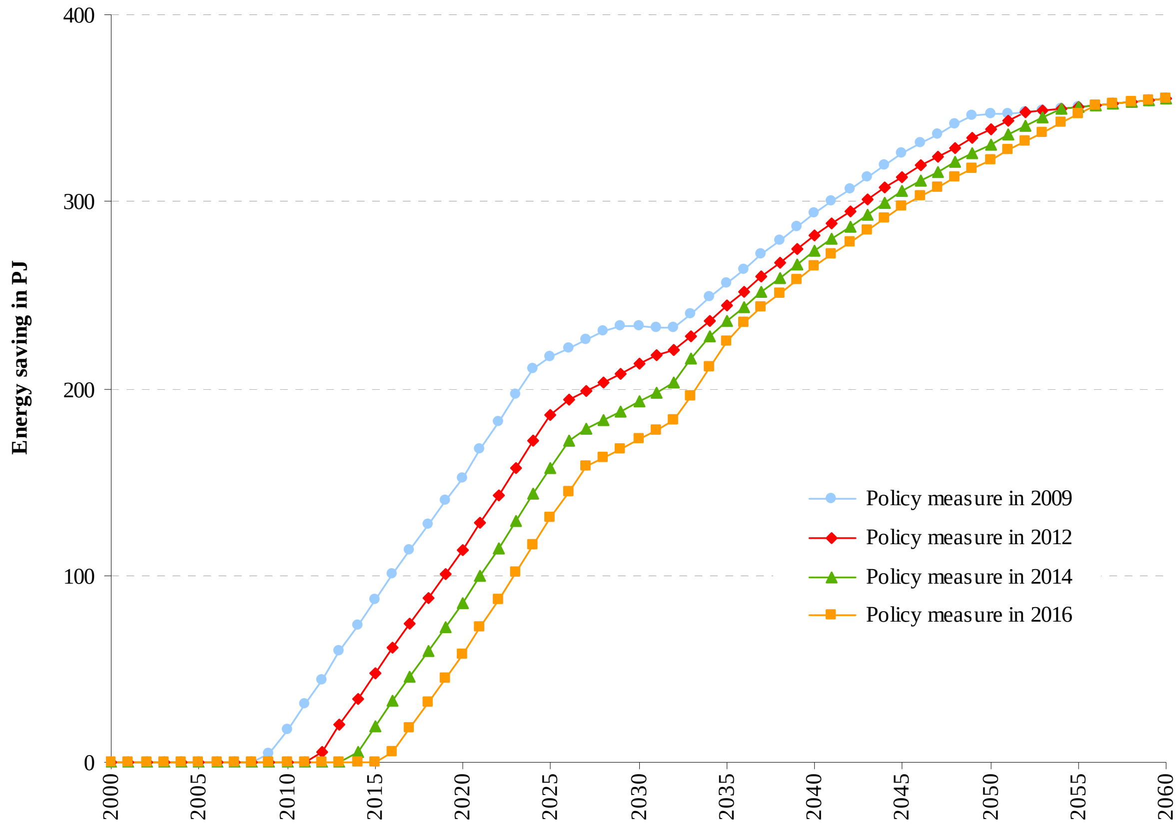

Figure 67 Energy savings for different timing options of the Full Coop scenario in Germany

The total additional investment is the same concerning the single years (Figure 68). However, total (cumulative) additional investment from 2000 to 2060 is smaller when the policy measure starts later (5 %, 9 %, and 12 % for implementation in 2012, 2014, and 2016, respectively).

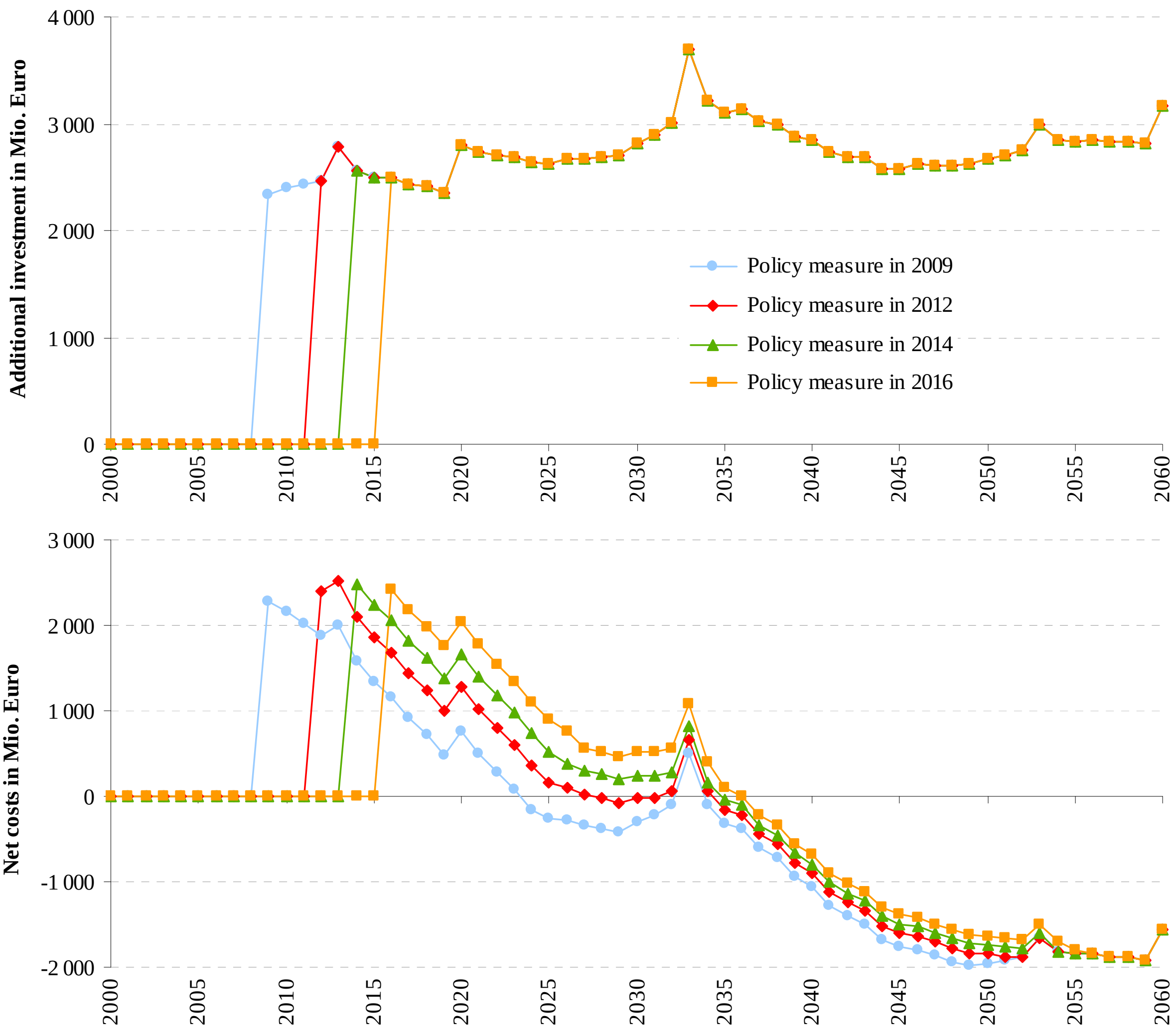

Figure 68 **Additional investment (top) and net costs (bottom) for different timing options of the Full Coop scenario in Germany**

The net costs for households vary in the first years between the different options. However, they converge following the convergence of the energy savings by 2055 to 2060. Average net costs from 2000 to 2060 are about -380 Mio. Euro/a in the policy scenario with the implementation starting from 2009.[25] When the implementation starts later, the net costs are increased to about -290, -230, and -170 Mio. Euro/a, respectively for 2012, 2014, and 2016.

The timing of policy measures thus is an important aspect to be kept in mind. As shown by the sensitivity analyses, energy savings, investment needs, and thus net costs of policy scenarios might differ considerably when measures are implemented in different years. However, the general conclusions of the modelling results remain valid: In the case shown, the net costs for the Full Coop scenario are higher when the measure is implemented later, but still negative, i.e. the policy scenario pays off for households.

[25] This means that, on average, the energy cost savings exceed the additional investment needs.

9.4.4 Reducing ventilation losses

The reduction of ventilation losses is a cost-efficient way to improve the energy efficiency of buildings [Nemry et al. 2008]. To reduce the ventilation losses, in general, self-adhesive caulking strips of expanded plastic are added on the window frame and other parts of the house where high ventilation losses occur.

According to [Nemry et al. 2008], the cost of this measure is about 3 Euro per m^2 living area (including taxes). In this study we assumed a cost of 5 to 10 Euro per m^2 living area in order not to underestimate the costs. It was assumed that by reducing ventilation losses, the air exchange rate could be reduced to between 1.0/h to 0.5/h which is still within the recommended levels for living rooms [Nemry et al. 2008].[26] An additional assumption has to be made on the duration the ventilation losses are reduced because the sealing deteriorates in the course of time. It was estimated, that the addition of sealings has to be repeated every 5 to 10 years.

The energy demand for space heating was calculated using the building stock model and EPIQR (see Sections 5.3.2 and 6.2) both for a reduction of the ventilation rate to 1.0/h and to 0.5/h. In Germany, on average, the calculated energy savings range from 490 PJ to 970 PJ per year which is comparable to the energy savings due to cost optimal renovation & refurbishment or the energy savings due to the EPBD recast or the Full Coop scenario (see Section 3.1 and Section 3.2). The associated costs were calculated assuming that the measure is applied to all buildings of the building stock.

The cost-efficiency of the reduction of ventilation losses for households was then calculated for all possible combinations of costs, frequency and energy savings of the measure which range from costs of 10 Euro/m^2, a frequency of 5 years (which means that annually, the measure is applied to 20 % of the building stock) and a reduction of air exchange rate to 1.0/h as low end and costs of only 5 Euro/m2, a frequency of 10 years and a air exchange rate reduction to 0.5/h as a high end of costs.

The net costs (additional cost of the measure minus the energy cost savings) of the measure are shown in Figure 69 as an example for Germany. For all of the eight possible combinations, the net costs are negative, except for the assumptions for the high end (low energy reduction & high costs). The net costs of the reduction of ventilation are comparable to the net costs of e.g the EPBD recast or the Full Coop scenario (see Section 9.1.8). Most probably, the reduction of ventilation losses is even more cost-efficient than the measures applied in the EPBD recast and Full Coop scenarios (major renovation and refurbishment of roofs and walls).

[26] A minimum air change rate is essential for the provision of oxygen and to reduce the level of CO and CO_2 in a room. In addition, a minimum air change rate is needed in order to reduce the relative humidity and the risk of moulding.

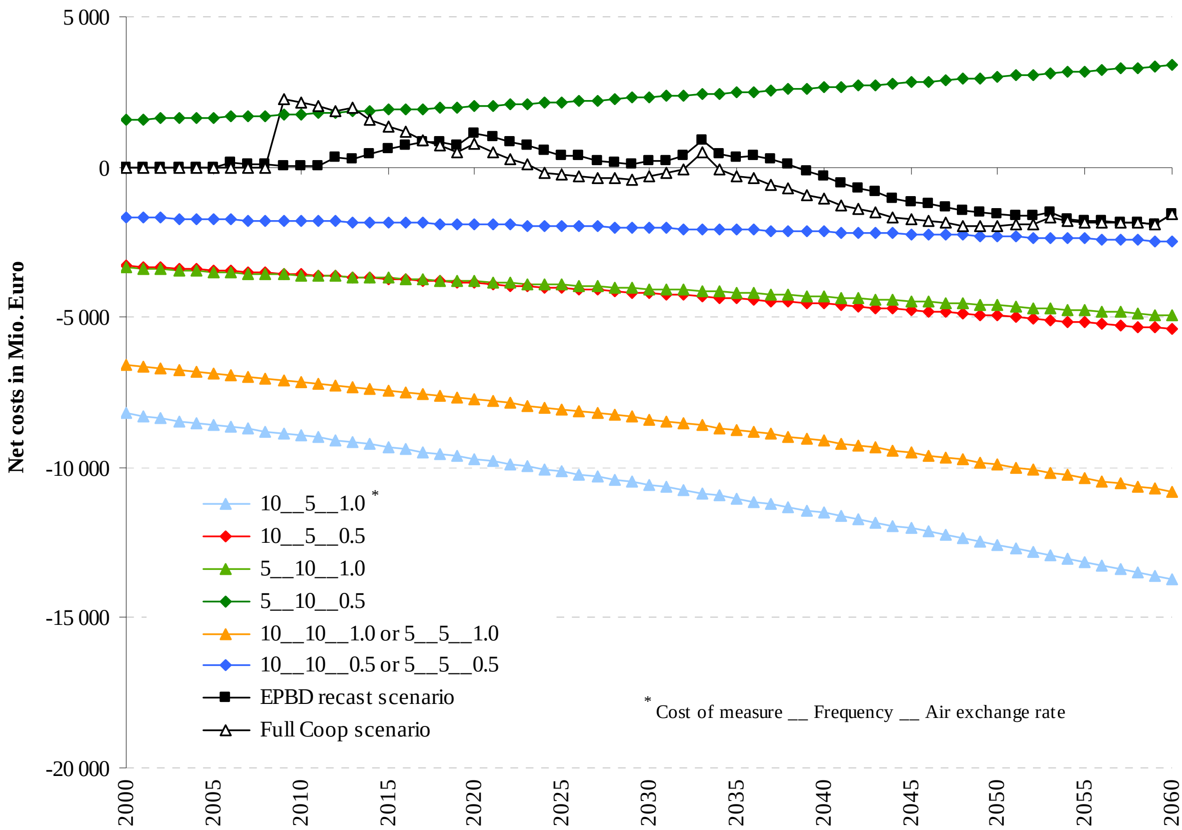

Figure 69 **Net costs (additional cost for insulation minus energy savings) of the reduction of ventilation rate including taxes for different assumptions in Germany**

From the sensitivity analysis performed, we can conclude that besides the different measures included into the policy scenarios, there might exist other measures that offer significant potential for energy and GHG emission reductions at low or even negative net cost. Other measures that one may think of include e.g. insulation of floors and interior walls.

10 Summary of the main results and conclusions

In this chapter, we will summarise the main results from the policy scenario analysis performed in this study. The conclusions that have been derived will be presented. In Section 10.1, we will show the reduction potential of energy demand for space heating in households as well as the net costs of the policy scenarios. The assessment of the socio-economic impacts on the economy and the GHG emission reduction potential will be summarised in Section 10.2.

10.1 Energy demand reduction and net costs

The energy demand for space heating can be reduced considerably in all policy scenarios in all countries (Table 59). On average, the energy demand savings are greatest for the policy scenarios that imply cost optimal renovation and refurbishment (Full Coop & Full Coop Acc). Also, the faster replacement of roof & windows (Coop Acc RR&WR) lead to a high reduction potential. Energy savings are bigger when windows only are replaced when compared to the energy reduction potential of the replacement of roofs only.

On average, the relative reduction potential is greatest for Spain which is mainly due to a low initial energy efficiency level of the building stock (and other reasons like e.g. climatic conditions, or the share of different building types). Relative savings are smaller in Poland compared to Germany, mainly because the cost optimal energy efficiency level assumed is less efficient than in Germany. For example, a U-value of 1.6 for windows was assumed in Poland while for Germany, a U-value of 1.2 was assumed to be cost optimal (see Section 5.3.2). The ranking of the absolute annual energy savings follow the size of the building stock of the countries.

Table 59 Average annual reduction potential of energy demand for space heating according to country and policy scenario from 2000 to 2060

Country	Full Coop	Full Coop Acc	EPBD Recast	Coop RR&WR	Coop Acc RR	Coop Acc WR	Coop Acc RR&WR
			Average annual reduction potential in PJ				
Germany	204.1	225.1	157.3	176.6	166.8	184.5	193.9
Poland	50.8	55.6	40.5	45.4	42.6	47.1	49.3
Spain	54.8	62.4	38.7	48.7	43.2	51.0	54.7
			Average annual reduction potential in % compared to reference				
Germany	9.9	10.9	7.6	8.5	8.1	8.9	9.4
Poland	7.4	8.1	5.9	6.6	6.2	6.8	7.1
Spain	10.1	11.5	7.1	9.0	8.0	9.4	10.1

The net costs – the additional expenditure for refurbishment or renovation minus the saved energy costs – for households (which includes all taxes) have been calculated for all policy options. In general, the policy scenarios lead to higher net costs in the first years due to higher investment in energy efficiency while in later years the energy cost savings offset the additional investment needs.

In Figure 70, the policy scenarios are depicted according to average change in net costs and average energy reduction potential. Clearly, the accelerated scenarios show positive net costs (i.e. the measures do not pay off) in all countries. Negative net costs can be achieved with the Full Coop, Coop RR&WR and EPBD recast scenarios. In terms of net costs, the Full Coop scenario leads to the best results.

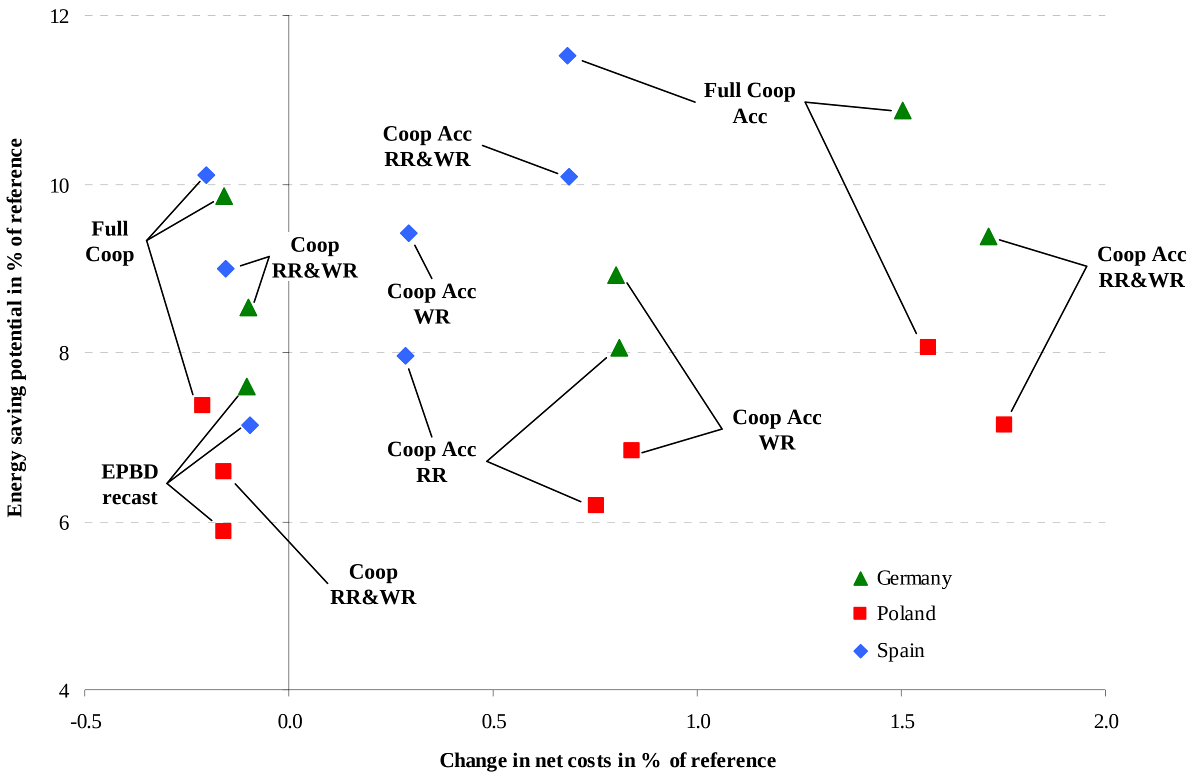

Figure 70 Average change in net costs and energy saving potential according to policy scenario and country

There exists no clear ranking of the size of the relative changes in the net costs compared to the reference according to country. For example, in the Full Coop scenario, the relative changes are greatest in Germany, followed by Spain and Poland. In the Full Coop Acc scenario, the changes are most pronounced in Poland, followed by Germany, and Spain.

10.2 Economy-wide impacts

The economy-wide socio-economic impacts that were assessed include the effects on e.g. value added, employment, or the compensation of employees. In addition, the GHG emissions of the whole economy (industry and households) were calculated for all policy scenarios.

In the following, we will focus the presentation mainly on average results (e.g. from 2000 to 2060). It has to be kept in mind, however, that the socio-economic impacts depend very much on the year, especially in the case of the accelerated scenarios. Also, we will discuss mainly the results for the 'default' financing option 1 while we also analysed four other financing options (see Section 7.3).

To show an example for the bandwidth of results for different financing options and the development of the impacts over the years, the impacts of two policy scenarios on employment are displayed as an example for Germany in Figure 71. We see that, especially for the accelerated scenario, the impacts vary significantly over the years and that they range from negative to positive employment impacts (Figure 71, top).

The same is the case for the variation between the different financing options. In the case of the EPBD recast scenario, the variation between the financing options is of the same size than the variation between the years (Figure 71, bottom). We have to mention that the financing options can be seen as extreme cases and thus serve as to illustrate the possible bandwidth of the socio-economic impacts.

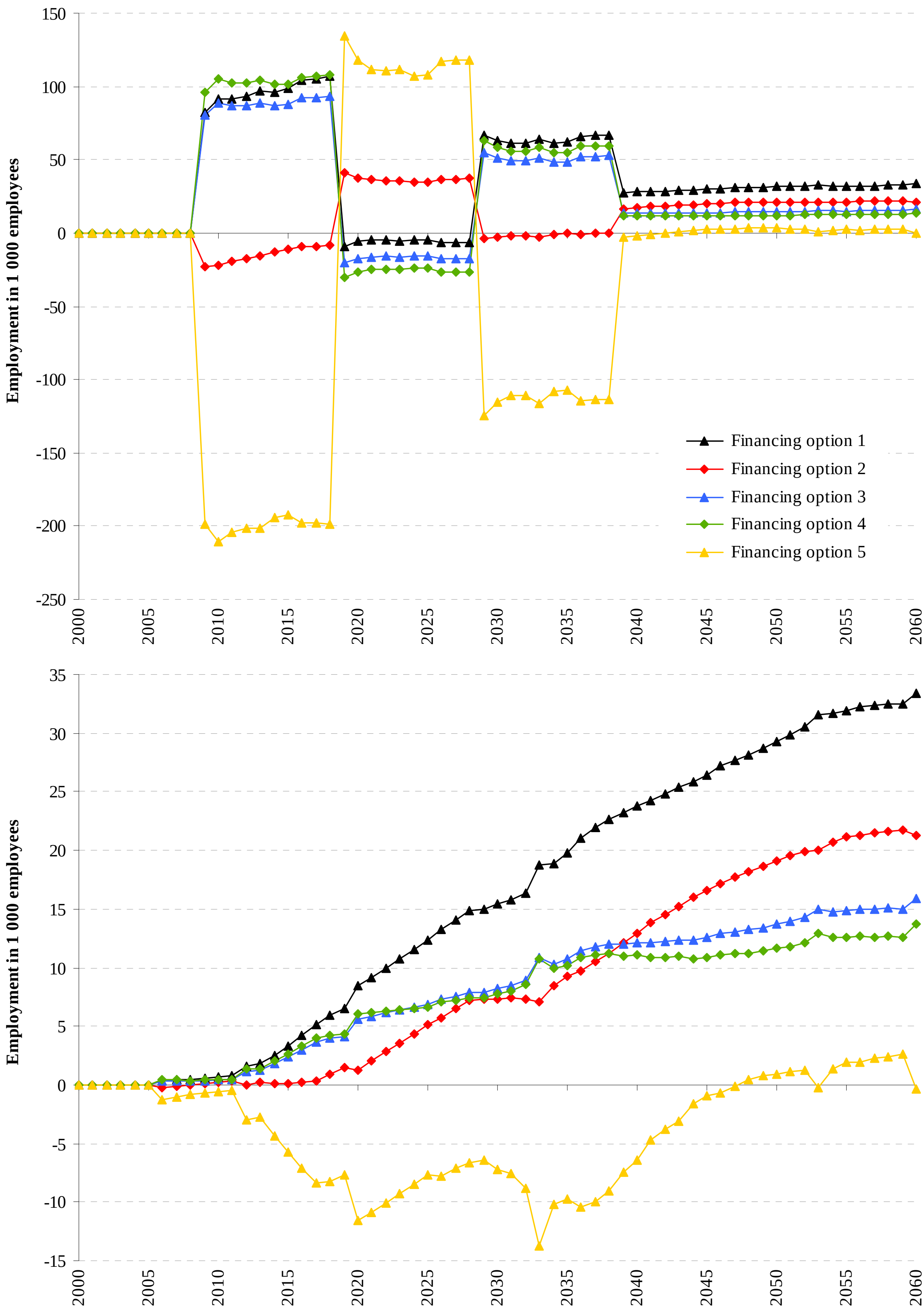

Figure 71 **Employment effects of the Full Coop Acc scenario (top) and the EPBD recast scenario (bottom) in Germany from 2000 to 2060 according to financing option**

The socio-economic assessment revealed that the impacts on employment, value added, and compensation of employees show similar patterns. We thus restrict our analysis to value added as the conclusions are valid for these two other parameters as well. Figure 72 shows the value added impacts of the policy scenarios according to country for financing option 1 and the bandwidth of the results for all financing options and years (which has to be seen as very extreme cases). All scenarios show a high variation over the years. The variation is also more pronounced for the accelerated scenarios. On average, all scenarios lead to positive value added. However, for individual financing options, and depending on the year, the impacts can range from negative to positive results. On average, the Full Coop Acc scenario leads to highest impacts, followed by the Coop Acc RR&WR scenario in Germany and Poland, and the Full Coop scenario in Spain. Regarding the ranking of the other scenarios, no clear statement can be made as the results vary between the countries. This also shows that there is a clear need to analyse the impacts of a policy scenario for every country as the impacts vary from country to country depending on e.g. climatic conditions, or the initial energy efficiency level of the building stock. In addition, with respect to the socio-economic impacts, also the structure of the economy influences the results.

However, we have to remind that the input-output model assumes instantaneous adjustment of the economy following an external shock in e.g. final demand which implies e.g. full labour mobility across sectors and adjustment of capital stock at zero cost. Thus, the model might overestimate socio-economic effects.

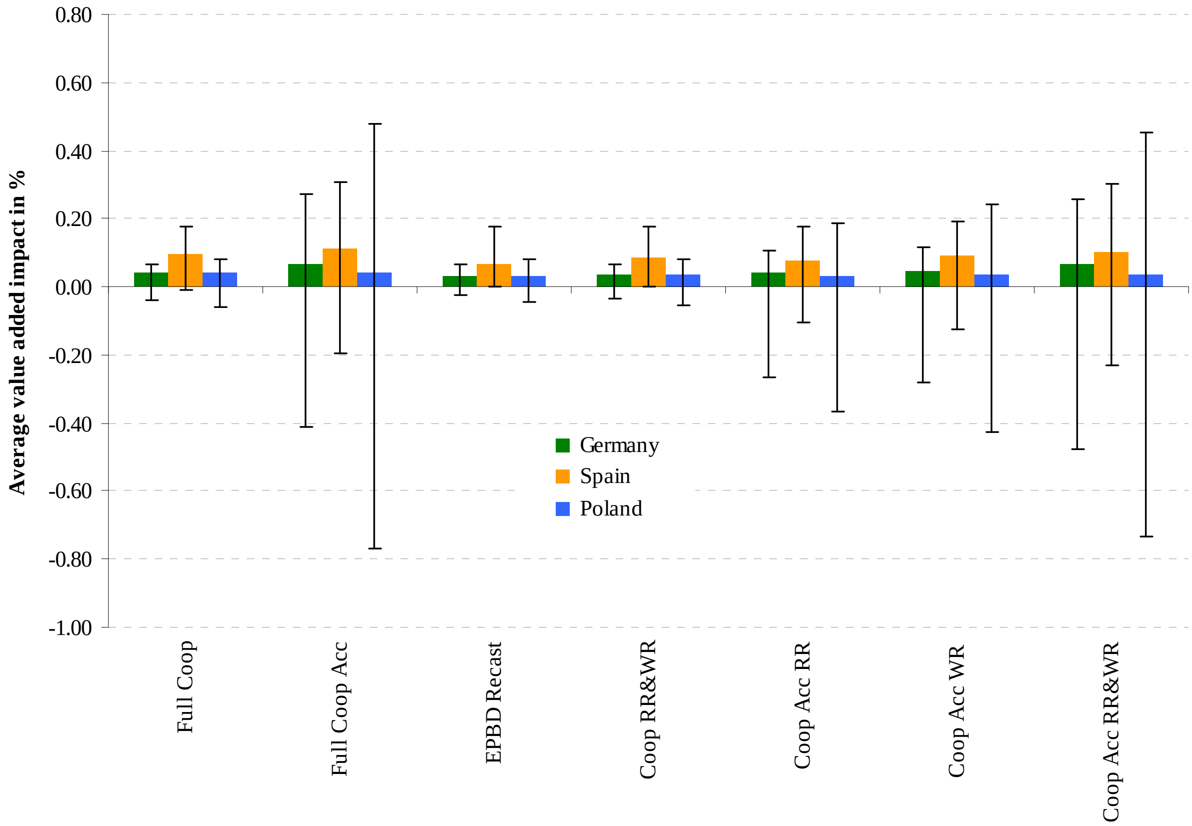

Figure 72 **Average value added impacts from 2000 to 2060 according to policy scenario and country for financing option 1**
The error bars display the range of the impact for all the single years and all financing options

The average welfare effects of the policy scenarios are displayed in Figure 73 according to country. Again, clearly the bandwidth of the results is greater for the accelerated scenarios than for the non-accelerated scenarios. The welfare effects range from negative to positive for all scenarios in all countries. However, the expected effects are small and lie in the percentage range (from about -1.5 % to about +1 %). In Germany and Poland, the best results are for the Full Coop scenario, followed by the Coop RR&WR and the EPBD recast scenario. In Spain, the best scenario is the Full Coop scenario, too, followed by the Full Coop Acc and the Coop RR&WR scenario. Differences between the policy scenarios are, in general, smaller than the variations between single years.

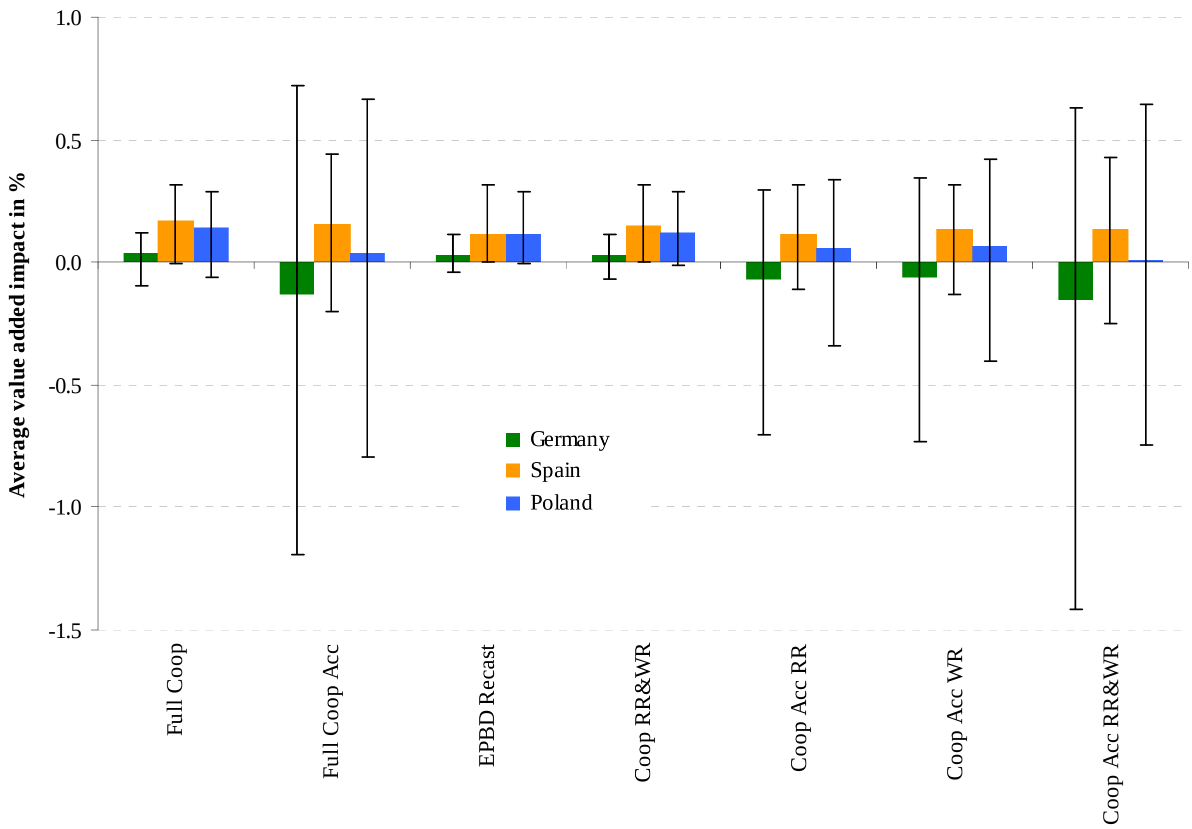

Figure 73 Average welfare effects from 2000 to 2060 according to policy scenario and country for financing option 1
The error bars display the range of the impact for all the single years

Figure 74 shows the average absolute greenhouse gas emission reduction potentials for the whole economy (households & industry) according to countries. Absolute emission reductions are greatest in Germany, followed by Spain, and Poland (which correspond to the respective size of the building stock of the country). Relative savings reach from can reach up to about 4.0 % in Germany, 6.6 % in Poland, and 2.1 % in Spain. The potential energy and GHG emission savings depend mainly on climatic conditions, and the initial energy efficiency level of the building stock.

The variation on GHG emissions between the financing options is small (Figure 74). This is because it the emission reductions are not driven by industry but mainly by the emission savings in households. Thus, the financing option does not show a major influence on GHG emission reductions. However, the financing option is important concerning the socio-economic impacts (see above).

The greatest average relative and absolute emission savings can be achieved by the Full Coop Acc scenario, followed by the Full Coop and the Coop Acc RR&WR scenarios in all countries and independent of the financing option. The acceleration of roof refurbishment leads to higher savings than the acceleration of window refurbishment with the Coop RR&WR scenario being in between.

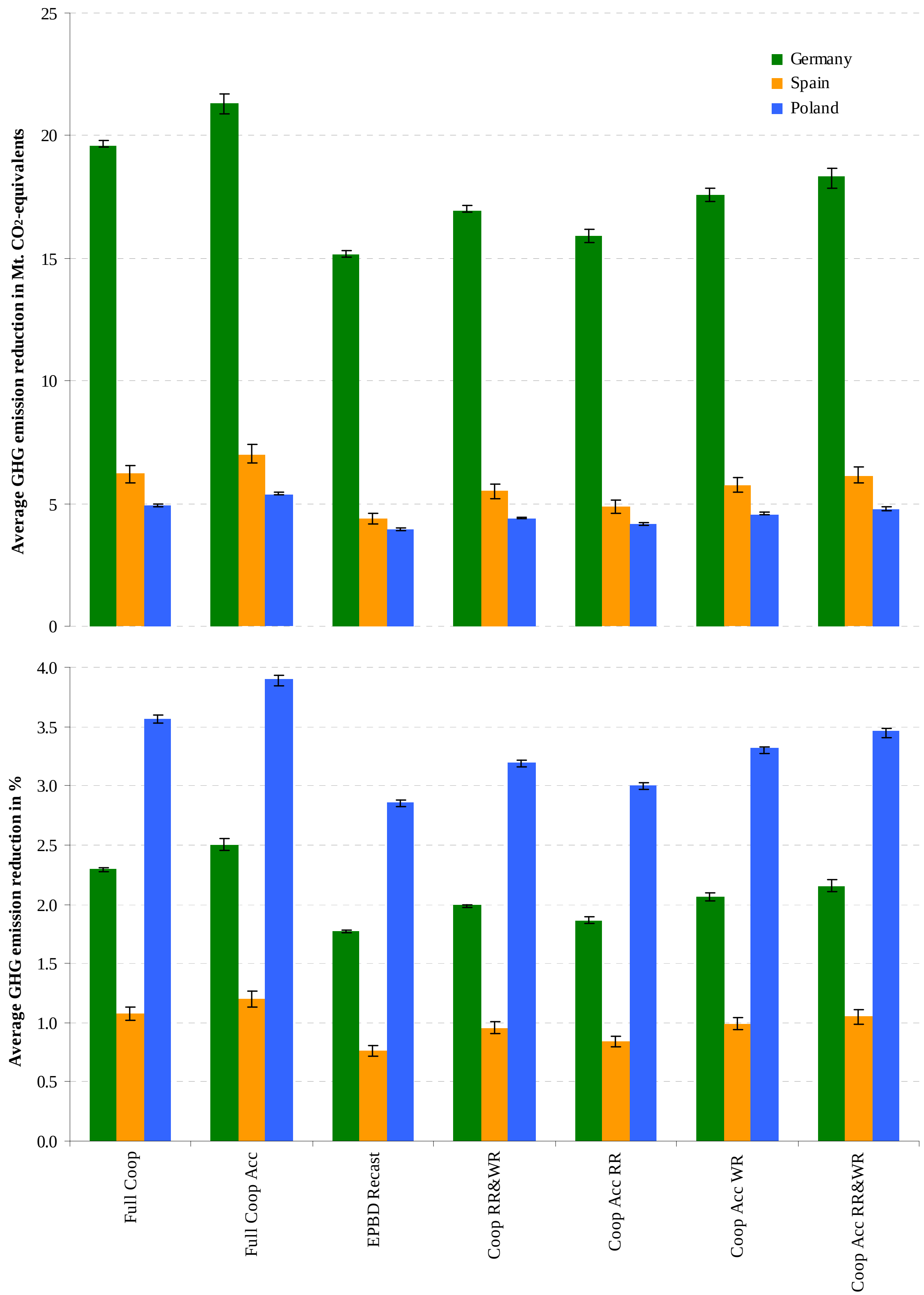

Figure 74 **Average annual absolute (top) and relative (bottom) GHG emission reduction potential from 2000 to 2060 according to policy scenario and country for financing option 1**
The error bars display the range of the impact for all financing options

An overview over the average GHG emission reduction potential and the associated socio-economic impacts is given in Figure 75 for the different policy scenarios analysed.

In Germany and Spain, clearly, the accelerated scenarios lead to worst welfare effects on average. In Germany even negative impacts are to be expected. The best scenario with respect to welfare is the Full Coop scenario, followed by the Coop RR&WR, and the EPBD recast scenario. In Poland, there is no clear preference in favour of or against the accelerated scenarios concerning the welfare effects. The best scenario is the Full Coop scenario, followed by the Full Coop Acc, and Coop RR&WR scenarios.

When we look at the average value added effect, the Full Coop Acc scenario leads to highest impacts for all three countries. The ranking of the other scenarios varies between countries. In general, also the Full Coop scenario and the Coop Acc RR&WR scenario lead to good results.

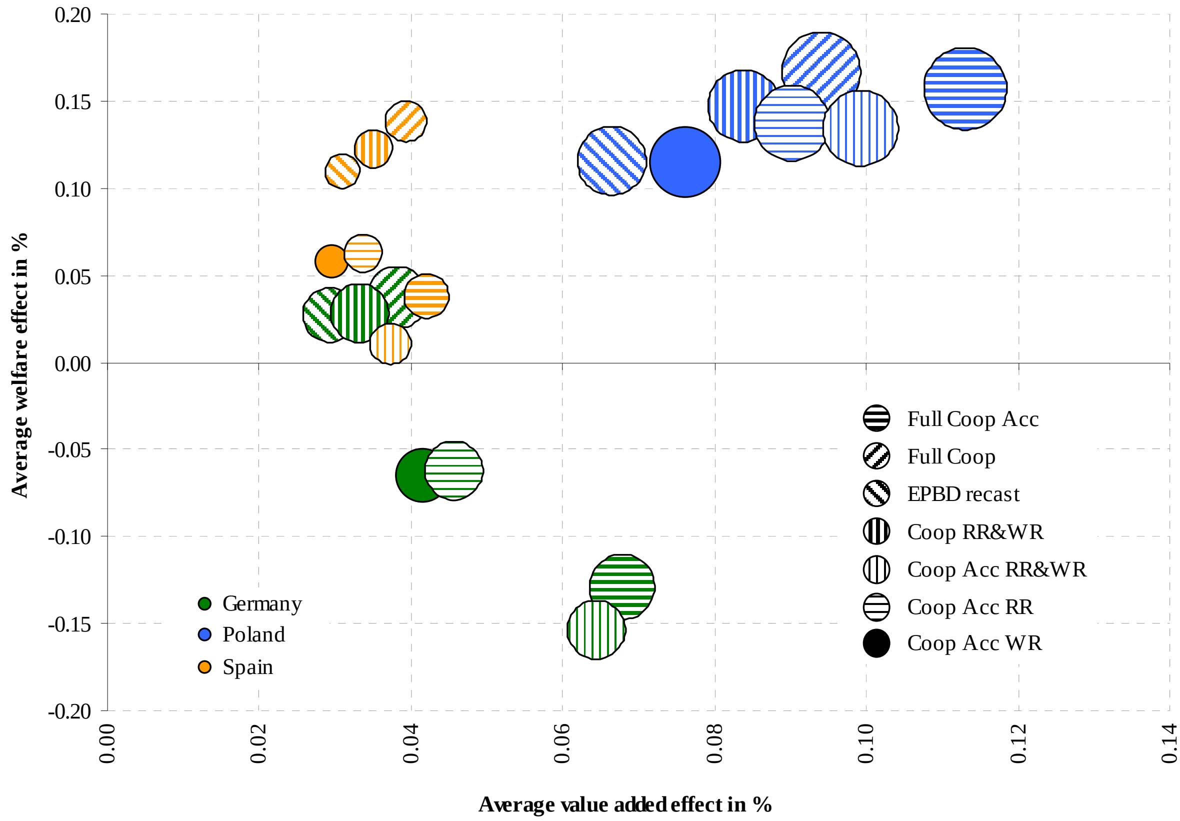

Figure 75 Average value added and welfare effect in % compared to reference according to policy scenario and country for financing option 1
The size of the bubbles correspond to the relative GHG emission reduction potential

To conclude, it is recommendable to ensure that building elements are always installed at cost optimal level whenever they have to be replaced anyway. This applies to major renovations and the refurbishment of individual building elements like roof and windows. The corresponding policy scenario (Full Coop scenario) shows negative net costs for consumers in the long term. Also, the socio-economic impacts of this scenario are quite small and – for a majority of indicators – positive.

If the replacement of building elements is accelerated, the energy saving and emission reduction potential is considerable. These measures, however, are not very cost-efficient in general. Negative socio-economic impacts might occur, too. For certain countries, the accelerated retrofitting of single building elements might be recommendable but this has to be studied carefully in advance and in greater detail.

The analyses have shown that a policy measures will have different effects in different countries due to variations in climatic conditions, the energy efficiency level of the existing building stock, the construction and demolition activity in the past and in the future, and the typology of the building stock (e.g. share of high-rise buildings). An assessment of future policies towards energy efficiency in the building stock should thus always be preformed on a country-by-country basis like it was done this study. Also, the building stock in this study was represented by generic building type models. Thus, the conclusions do not allow to infer any recommendations for individual buildings as they can deviate in important variables from our generic model types (e.g. current insulation level and orientation of the building, volume:envelope ratio, heating system). A detailed energy analysis should thus always be performed in order to derive the appropriate measures for a specific building.

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Abstract

This report supports EU policymaking on sustainable consumption and production (SCP) in the area of buildings, which were indentified as being particularly relevant for environmental improvements. Various policies exist or have been proposed at EU level to improve the energy efficiency and thus the environmental performance of buildings. However, these policies address mainly new buildings and major renovations of existing buildings.
Previous research has shown that – on top of the policies already in place – there is the potential for additional policies to lead to further reductions in the environmental impacts. Improving the energy efficiency of certain building elements such as windows and roofs independently of major renovations of whole buildings was identified as potential main target of such additional policies.
This report presents the quantitative assessment of the possible environmental and socio-economic effects of such policy measures. In particular, two types of measures addressing the energy efficiency of building elements are assessed: 1) requiring high energy efficiency standards (thermal insulation levels) when individual building elements have to be renovated, and 2) accelerating the retrofitting of individual building elements according to high energy efficiency standards. The results of the modelling show that additional policies could deliver further substantial savings of energy and greenhouse gas emissions and that the socio-economic benefits would outweigh the costs.

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